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G. E. McELROY

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DEPARTMENT OF COMMERCE - BUREAU OF MINES

MINE VENTILATION IN THE COEUR D'ALENE MINING DISTRICT[1]

By G. E. McElroy[2]

INTRODUCTION

The Coeur d'Alene mining district of Shoshone County, Idaho, has been one of the largest and most active lead-silver producing districts in the United States for the last 40 years. The mines of the district enjoy exceptional natural advantages with respect to ventilation in that the veins apex high on mountain sides and are most often developed to considerable depths, up to 2,000 feet, by adit and crosscut tunnels under conditions that develop large natural draft pressures; the increase of temperature of the rock with increase of depth from surface is at a low rate; and the average surface temperatures are low. These natural conditions have, in the main, resulted in well-ventilated mines with low temperature conditions throughout.

However, where the development has been carried to considerable depths below the lowest level of surface entry, natural-draft ventilation has proved inadequate, and mechanical ventilation systems have been installed on the three largest mines of the district. Local conditions, more particularly those in dead-ended working places, have also required auxiliary ventilation by small fan-pipe units in these and other mines. A particular feature of the district is the number of exceptionally long crosscut tunnels that have been driven to provide entry to vein systems from low points adjacent to milling and transportation facilities. Three of these tunnels are approximately 2 miles long, and lengths of 3,000 to 8,000 feet are quite common.

As part of a more general and country-wide study of metal-mining methods, the Bureau of Mines is engaged in a limited study of methods and costs of ventilating metal mines. This paper discusses methods, practices, and costs in the Coeur d'Alene district as obtained by brief personal surveys during May and June, 1930, and from supplementary information furnished by the managements. The study was devoted almost entirely to the three large mechanically ventilated mines—the Bunker Hill and Sullivan, Morning, and Hecla—and but three of the smaller, naturally ventilated mines were visited—the Gold Hunter, Page, and Dayrock. Underground observations occupied about a week at each of the larger mines and a day at each of the smaller mines.

Detailed data regarding mining and ventilation conditions in the particular mines studied are preceded, in this report, by a section summarizing the mining conditions and another summarizing the ventilation conditions of the district as a whole.

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1 - The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6382."

2 - Mining engineer, U. S. Bureau of Mines.

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The author also wishes to acknowledge his obligations, for guidance and assistance underground and data on operating conditions, to the following persons: Hugh McDermott, director of the Central Mine-Rescue Station of the district; C. H. Foreman, chief engineer of the Hecla mine; L. J. Coady, chief engineer of the Morning mine; U. E. Brown, chief engineer of the Bunker Hill and Sullivan mine; S. E. Lavrov, mining engineer of the Page mine; J. F. Leonard, superintendent of the Gold Hunter mine; and M. S. Murray, foreman of the Dayrock mine.

The few mine-air samples taken during this study were analyzed at the Pittsburgh station of the bureau under the direction of W. P. Yant, supervising engineer of the health-laboratory section.

MINES AND MINING CONDITIONS

Although the boundaries of the Coeur d'Alene district are indefinite, the name generally refers to a district extending about 40 miles east and west and roughly 10 miles north and south, centering on the town of Wallace, and extending from Pine Creek gulch a few miles west of Kellogg, through Wallace to the Montana line a few miles east of the towns of Mullan and Burke. It embraces the headwaters of the South fork of the Coeur d'Alene River, which is joined at Wallace by Canyon Creek.

Labor and Production

The district normally employs about 5,000 miners. Climatic and housing conditions are exceptionally good, and the district is essentially a "white man's" camp, employing a large proportion of native-born miners. This area supplies practically all of the mine production of Shoshone County which averages about 90 per cent of the production of the State - second in the United States in production of lead and third in production of silver. The district also produces important quantities of zinc and some copper and gold. The Shoshone County assessor's records for 1929 show a gross value of $25,658,061 for the district's production and net profits of $7,691,090. This production was but little larger than the average for the last seven years. Net profits for 1928 are reported as $6,842,499, and for 1927 as $7,139,888. The bulk of the production and net profits for the last few years has been contributed by three large mines, the Bunker Hill and Sullivan, the Morning, and the Hecla, but eight to ten other mines have contributed what would ordinarily be considered important productions--roughly, 50,000 to 100,000 tons a year each—and the State mine inspector's report for 1929 lists 50 producing mines.

Ore Occurrence

The main ore deposits are lead-silver-zinc fissure veins cutting sedimentary

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quartzites at an angle both in strike and dip. Several of the major vein systems are practically vertical, while others lie at rather flat angles, usually about 40°. Strikes and dips are fairly regular, as a rule, but widths are very erratic. The principal ore occurrence is in the form of roughly parallel veins and stringers of clean galena, or galena and sphalerite, with mineralized zones often attaining great widths over considerable lengths. Usually, the footwall is well defined, but the hanging wall is indefinite, and minor oreshoots lead in and out of the main mineralized zone. Where the veins are vertical, the adjacent quartzites are sheeted paralleling the vein and on exposure develop tremendous side pressures which have much to do with determining the details of mining practice. As a rule, the flat-lying veins occur in good ground and offer no particular difficulties except where large masses are mined.

Mine Openings

The whole district is very precipitous mountain country intersected by numerous gulches leading off the main narrow valleys. Vein apexes are roughly 4,000 to 6,000 feet above sea level, but most of the operating openings are at elevations of 2,500 to 4,000 feet and the lowest operations in the three large operating mines are within 1,000 feet of sea level. As a rule, the initial prospecting and development of the veins is by adit drifts off the sides of steep gulches with successively lower lifts until the limiting depth of the gulch is reached. Then, if sublevel development justifies, a long crosscut tunnel is driven from one of the major valleys. Certain properties have been developed directly by long crosscut tunnels and a few by surface shafts. The more general condition is an interior shaft off either a long drift adit or off a long crosscut tunnel.

Mining Methods

Mining methods of the three larger mines have been covered in detail by the technical press and in recent information circulars of the Bureau of Mines. Although shrinkage and open-stope methods without fill have been used to a limited extent, practically all of the present operations employ waste filling in conjunction with square-sets designed to better resist side pressure. Waste filling is obtained largely from wall raises and crosscuts. As a rule, the openings to and through stopes are relatively large as compared with ordinary square-set mining in heavy ground. Floors in stopes are 7 to 9 feet high, and three or more floors are usually open at a time.

All mine openings are generally larger than the average for metal mines, particularly raises in stull-set mining. The use of long large-diameter cap timbers in stoping is quite common, and the provision of timber slides for handling them usually results in large-area openings for stope air flow.

VENTILATION CONDITIONS

Ventilation by Natural Draft

The ventilation of the mines of the district, in their initial and intermediate stages, has been a natural process requiring practically no effort on the part of the operators. With openings at several horizons and operations in low-temperature rock, the natural differences in temperatures, between the air columns in the mine and the surface air column, develop sufficient natural draft to produce good ventilation of the mines throughout most of the year. As is common in natural-draft mines, the currents reverse with the seasons and

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during two periods of the year, usually about June and October, are small and variable in direction. However, where comparatively large differences in elevation of surface openings are involved, the quiet periods are of short duration, and, with work usually on only one shift, occasion few difficulties. Long dead ends, particularly the exceptionally long cross-cut tunnels, are usually ventilated by small fan units, but the more customary method of ventilating dead ends is to blow sufficient compressed air at the face between shifts to clear the opening before the succeeding shift enters.

History of Mechanical Ventilation

When the workings were all above the lowest surface openings, ventilation conditions are reported to have been uniformly good throughout the district except that cold wet working places were difficult to avoid, even though surface openings were throttled to a large extent during mid-winter. As workings progressed below lowest surface openings, natural drafts still provided fair ventilation of these lower workings, although the need for control was gradually recognized and, in some cases, was applied. Stopes below the lowest surface opening but near the top of ascending currents were the first to develop markedly poor air conditions due to heat and air vitiation resulting from timber decay and chemical reactions between air, water, and ore constituents. By 1914 the need for mechanical ventilation was recognized at both the Bunker Hill and Sullivan and Morning mines, and raise systems were started for this purpose. Scarcity of workers just before and during the war somewhat hampered operations, but the first unit for primary mechanical ventilation was installed at the Morning mine in February, 1918, and at the Bunker Hill and Sullivan mine in December of the same year.

The Hecla mine, with a more concentrated layout, a more effective control of natural drafts, and better natural conditions as to rock temperatures and air vitiation, operated to the 1600 level with but a few hundred feet of surface natural draft column, but conditions were considerably improved when a raise from an interior ore body was driven to surface and the surface air column was increased to 1,500 feet. As the extensive 2000-foot level was opened up, conditions were still fair, except for occasional intervals. Mainly to take care of these intervals and to improve the ventilation of upper levels, a reversible surface exhaust fan was installed in July, 1925. The desire for more effective control of air-currents at time of mine fire was an important consideration in its installation, as was also the desire to reduce timber decay on certain levels by preventing reversal of direction of flow.

Since the original installations, continuous extensions and improvements of the ventilation systems have been made which are outlined in more detail later in this report under the headings of the respective mines. Primary mechanical ventilation has been applied only to these three mines.

Auxiliary Ventilation.- Auxiliary ventilation of long dead-ended working faces antedates primary ventilation in the district by at least 10 years and has been used, though to a rather slight extent, by most of the producing and development companies. Extensive use has been made of auxiliary ventilation units in the Morning mine, where natural conditions have led to their introduction. Small booster fans operating in series-parallel combinations on the primary circuit are also used. Under the low-temperature conditions prevailing in the district, the rapid removal of blasting smoke has been the primary consideration, and the natural choice of apparatus has been the small units operating as exhausts in conjunction with small-diameter galvanized-iron pipe. Under the higher temperature conditions encountered in the three deep operating mines, larger units operate as blowers in

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conjunction with larger diameter canvas and galvanized-iron tubing. In the Morning mine, compressed-air injector blowers are also used, with short lengths of canvas tubing, for local air motion and for auxiliary ventilation of short dead ends.

Distribution Systems

In general, the ventilation of the smaller mines takes care of itself to a great extent, in that the normal openings required for operating the mines provide plenty of opportunity for the circulation of natural draft air-currents. Occasionally, it has been necessary to drive a raise to adjacent openings to insure circulation, but such steps have also been required to provide second exits for safety and are seldom very expensive undertakings. Very little control over natural draft currents is attempted. Observations made in several naturally ventilated mines indicate that although the amounts of air circulated by natural draft are quite large even under small temperature differences, the amounts carried to active zones of operation may be quite small. Depending on the particular layout, more or less recirculation is involved and much of the naturally coursed air short-circuits the active zones of operation, conditions that could be remedied in most mines where they occur by the installation of a few inexpensive doors.

The Bunker Hill and Sullivan mine has four fans in series underground which draw air from the surface, through old workings and a large 2-mile haulage tunnel, to the first level below the main tunnel haulage level. There it is downcast through an air raise to the lowest levels and returns through stopes and the two operating shafts to the same level, where it enters a return air raise connected to surface outlets.

The Morning mine has a fan underground on the main tunnel level which draws air in through a 10,000-foot crosscut tunnel to the main shaft. The shaft is shut off on all levels and serves as a supply chamber for auxiliary fan-tubing units which distribute the air to the stopes. The return air passes up a system of air raises to the fan which discharges it through another raise system connected to surface outlets.

The Hecla mine has a reversible surface exhaust fan which draws air down a main surface shaft to the 2,000 level and up through stopes and raises to a tunnel level which is connected to the fan.

Air Conditions

Mine Air Temperature.- The mines of the district are damp to wet, and the air throughout all of them is very close to saturation. Wet-bulb depressions are rarely more than 0.5°F. and relative humidities are usually 95 per cent or over. Except at great depths, the rock temperatures are low and air temperatures are also low. In the naturally ventilated mines and throughout the upper workings of the mechanically ventilated mines, the normal temperature range is about 45 to 60°, air velocities are very low, and the conditions are normally comfortable and cool. Occasionally, places are uncomfortably cold, but such conditions can usually be remedied by throttling the main intakes. Blasting is practically limited to the end of the shift and the four to 16 hours available is usually more than sufficient to clear the mines of all traces of blasting smoke and gases.

The lowest active zones of operation in the deep mechanically ventilated mines are uncomfortably warm in some degree but not to a degree that would occasion comment in mines

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of equal depth but less favorably situated as regards average surface temperatures and rock-temperature gradients, nor to a degree beyond the scope of ordinary methods of mechanical ventilation. Places with temperatures above the range of 75 to 82° are rarely encountered in these zones, although lower temperatures are quite common.

Surface Air Temperatures.- Due to the geographical location of the district, surface air temperatures are naturally low. The Idaho section of the 1929 annual report of the U. S. Weather Bureau gives the mean annual dry-bulb temperature for Kellogg at 2,305 feet, as 45.9°, and for Wallace, at 2,770 feet, as 45.4°. The record for 1929 at Mullan, at 2950 feet, is 2° lower than at Wallace, and Burke, at 3,700 feet, must be at least 3° lower than at Wallace. Even lower mean annual dry-bulb temperatures must exist at many of the surface openings of the mines of the district.

No data on mean annual wet-bulb temperatures are available, but they are estimated to be somewhere between 5 and 10° lower than the dry-bulb figures.

Rock Temperatures.- The predominating factor in securing such low temperatures at great depths is the low rates at which the rocks of the district increase in temperature with increase in depth. The gredients have been roughly determined as varying from 1° per 150 to 180 feet, whereas in the average mining district the gradients are more likely to be under 1° per 100 feet than over.

Air Quality.- Three air samples taken in three naturally ventilated mines in places where maximum vitiation, due to distance from intake, low-volume supply, and recirculation, would be expected, show good-quality air.

Numerous samples of air from the mechanically ventilated mines show similar conditions except where the air has traveled through old stopes; the samples then show rather unusual excesses of carbon dioxide and a lowering of the oxygen content. In certain cases, the air vitiation is of sufficient extent to affect labor efficiency, but not to an extent that would cause any physiological reactions except fatigue.

Timber-Decay Fungi

All of the mines visited showed timber-decay fungi prevalent practically everywhere and to an extent that would probably be more serious if timber were not relatively cheap and abundant. Conditions present a noticeable contrast to mechanically ventilated mines in the Southwest where timber-decay fungi are, for the most part, limited to certain return-air sections and in many mines are almost nonexistent. Apparently such fungi breed best under the conditions obtaining in naturally ventilated mines—low-velocity saturated air currents, frequent zones of precipitation and frequent reversals of direction of flow. In the mechanically ventilated mines of the district the spores of timber-decay fungi have been carried down to more recent workings from old upper workings. In the Hecla mine, however, where surface air is now carried directly to lower operating zones through a wet shaft, these fungi are present in abundance only on old upper levels.

In this connection, the writer has noted, both in this and other mining districts, a particular abundance of such fungi, more often of the white variety resembling cotton, at the junction of air currents where precipitation of moisture takes place either with or without the accompaniment of visible fog.

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Doors on Surface Openings

The district has had considerable experience with fires adjacent to surface openings, and in the majority of mines, doors are provided on such openings so that they may be closed in case of surface fires.

Intake air currents cause considerable trouble during exceptionally cold winter weather from freezing of water in pipes and drainage ditches, and a further use of doors on surface openings is to limit such troubles to a minimum. In the naturally ventilated mines, doors such as these represent practically the only attempts made to control the distribution of air-currents by natural drafts.

BUNKER HILL AND SULLIVAN MINE

The Bunker Hill and Sullivan mine of the Bunker Hill and Sullivan Mining and Concentrating Co. is operated through a 2-mile crosscut tunnel, at an elevation of 2,400 feet, at the west end of the town of Kellogg. The vein outcrops are in gulches above the adjoining town of Wardner, with the highest openings about 1,400 feet higher than the Kellogg tunnel level. The latter is practically the top of the present mine, although there is some company work and a considerable amount of leasing in old sections, covering an extensively worked area about a mile and a half long by 1,500 feet wide, above this level. The tunnel is on the No. 9 level and the lowest working place is a winze now 200 feet below No. 19 level at an elevation of 200 feet above sea level.

The lead-silver ores occur in very complex vein systems in quartzite and vary from narrow fissures with good walls to very large irregular massive ore bodies with soft walls. Most of the deposits now worked comprise two main sets of veins whose strike, dip, and dimensions are quite variable. The Francis-Barr fissure veins strike about east and west and dip most often about 40 to 50° south; the Bunker Hill veins strike about 35° west of north and dip most often about 40 to 50° southwest. Operating lengths vary from 300 to 1,000 feet and widths from 2 to 125 feet. Average widths are about 5 feet for the fissure veins and 30 feet for the Bunker Hill ore bodies. Both occur with quartz gangue and accompanied by siderite, but to a slight extent only in the case of the fissure veins and east-side workings. Although quite close together just below the tunnel level, these two sets of veins diverge with depth and are about 2,500 feet apart on the lowest developed level, No. 19.

In May, 1930, company operations were producing about 1,400 tons a day of ore averaging about 10 per cent lead and 3.25 ounces silver per ton, with approximately 580 underground employees, of whom about 540 were working on the day shift. In addition, about 80 leasers were producing approximately 100 tons a day.

Mine Openings

Levels are opened at 200-foot vertical intervals, which give about 300 feet as an average distance between levels in the planes of the veins. Below the No. 9, or Kellogg tunnel level, these are developed off two inclined shafts on parallel planes about 500 feet apart. The No. 1 shaft, sloping at 50°, has three compartments and is used entirely for hoisting ore except at change of shift. The No. 2 shaft, sloping at 40° 35', has three compartments and is used entirely for transferring men and materials.

Transportation of men and materials to company operations above the tunnel level

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is through two 2-compartment timbered raises, the Dull and Cherry raises, to the No. 5 and No. 6 levels respectively. Ore mined in these operations is transferred through chutes to the tunnel level. Leasing operations are conducted mainly through separate surface connections.

Mining Methods

About 92 per cent of the stopes are mined by square-set methods in floors 7 feet high in the clear and with waste fill closely following extraction. Stope backs are arched with the highest point on the hanging wall, and stoping is by vertical cuts. Chutes are carried up on 20-foot centers and manways on 50-foot centers. Three-compartment raises are carried through to the level above as soon as the stope gets under way. At the start these serve for ventilation and for waste-filling operations, but after the stope is halfway up, they are used for transportation of men and supplies. About this time, many of the original manways are crushed so that although they still serve as airways they are no longer used as manways. The original chutes are also replaced, in large stopes, by rock chutes from rock drifts in the footwall.

In May, 1930, company operations were being carried on on all levels from No. 6 to No. 10, but major activities were below the No. 13 level. Ordinarily the full length of the mineralized area is carried up as a continuous longitudinal stope, and some are exceptionally long. At this time the equivalent of 40 large stoping sections were in operation, and development work consisted of four raises, a winze (off No. 19 level) and 12 drift and crosscut faces.

Ventilation History

The mine is mechanically ventilated by four underground fans operated in series. Air taken in through the Kellogg tunnel and the end sections of the old workings above the main-tunnel level, is coursed through the active stopes and discharged through the central section of the old upper workings.

Air conditions first became uncomfortable in the No. 10 to No. 13 level stopes. In the former, oxidation of pyrite in the ore was, and continues to be, a local cause of increased temperatures. Apparently timber decay and chemical action of the contained siderite were responsible for the high temperatures in lower large stopes, as rock temperatures were lower than air temperatures.

Large-sized rock raises were driven up to No. 10 level in the footwall on the west side previous to and during 1918, and late in that year a fan was installed on No. 10 level at the top of this raise system to blow air down to the lowest levels. The intake was through the upper west side workings and the return (from the shafts) up the upper east side workings. During 1919, another fan was installed on the No. 9 (tunnel) level at the foot of the Dull raise and connected by a raise to No. 2 shaft at a point below the collar. This fan discharged the return air up the raise to old workings connected to surface outlets. Conditions in some of the upper stopes were still far from satisfactory and in 1920 another fan was installed on the No. 10 level discharging into No. 2 shaft, which, with the installation of doors on the upper-level shaft connections, resulted in air flow through stopes that previously had very little. By 1929 the west-end air-raise system had been carried to the No. 16 level, but development had been carried to the No. 19 level. In this year another fan was added to the system to improve the circulation through the lowest stopes and was

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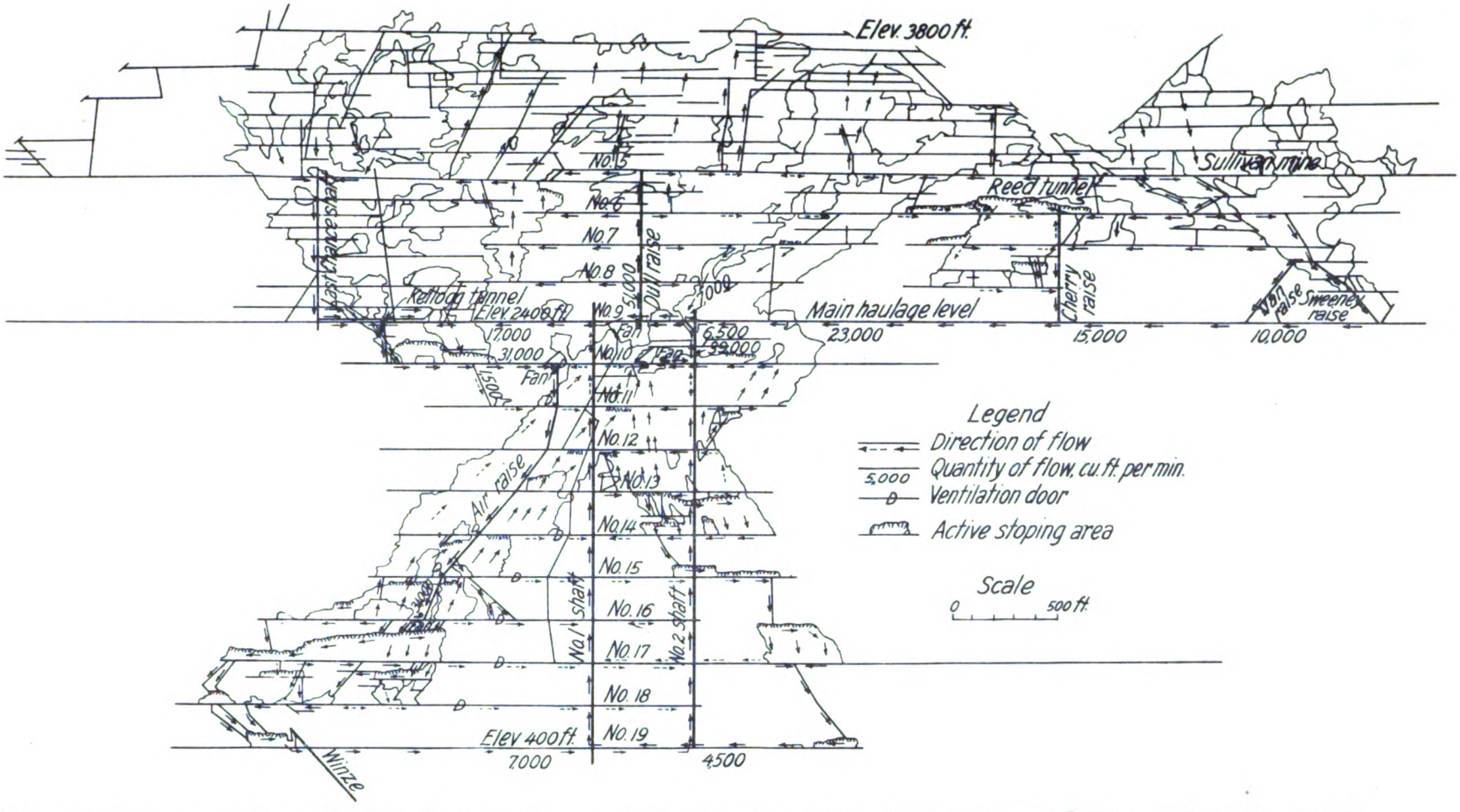

Figure 1.- Diagrammatic vertical section showing ventilation system of the Bunker Hill and Sullivan Mine, May, 1930

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placed at the foot of the air raise so as to draw air from the raise and discharge it through stopes above and below this level.

Distribution of Air Currents

The major elements of the air-distribution system, as determined by a brief survey in May, 1930, are shown on the vertical projection, Figure 1. Air enters through the old Sullivan workings on the east end, the old Last Chance workings on the west end, and, through the Kellogg tunnel except during warm summer days when it is a fresh-air outcast supplied by the Last Chance intake. The total combined intake passes down the air-raise system on the west side, through the action of fans on the top and bottom of the raise, to the No. 16 level where it splits; about a third continues down through stopes with main outlet across the No. 19 level to the bottom of the upcast No. 2 shaft, and the rest upcasts through stopes and both shafts, with considerable interflow between shafts and stopes, to the No. 10 level. At that point the total exhaust is collected and discharged by a fan through a short section of No. 2 shaft and a connecting raise to the bottom of the Dull raise on the No. 9 (tunnel) level, where another fan discharges it up the raise and out numerous surface connections.

The measured intakes, at the No. 10 level, totaled about 33,000 cubic feet per minute, to which was added about 4,000 c.f.m. of compressed air liberated below this level. The total effective air supply closely approximates 40,000 c.f.m., equivalent to about 75 c.f.m. per company man employed underground on the day shift.

The east side intake current crosses the No. 9 level from one end to the other and passes connections to both shafts and to both intake and discharge sides of the main discharge fan. The shaft connections are open, but the fan pressures are so balanced that only a relatively small amount short-circuits into the main return through the upper section of No. 2 shaft, and the No. 1 shaft connection is practically neutral with small flows changing direction with the movement of skips in the open shaft compartments. Some air leaks through a single door into the fan intake and some return leaks through the two-door airlock from the fan discharge. The net result of the interchange and the effect of travel along the haulageway is that the intake of 23,000 c.f.m. of 56° saturated air just east of No. 2 shaft was reduced to 17,000 c.f.m. of 68° saturated air at the point where it joined the other intakes.

On the lower east-side levels, natural draft between the warmer No. 2 shaft and the cooler stopes was resulting in the downcasting of a small split of air through stopes that, in any general layout, one would expect to be upcast.

Practically all levels have very extensive openings, and with few exceptions the travel of the air is at very low velocities. Many zones of open drifts and crosscuts are practically neutral in respect to air flow. Rock temperatures on upper levels are below air temperatures and foggy zones, due to mingling of practically saturated air currents of different temperatures, are quite common.

The mine makes a considerable amount of water, and practically all working places are damp to wet, although actual drippers are not of frequent occurrence.

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Performance of Main Fans

The four main fans are all American Sirocco (forward-curved-blade), single-inlet, single-width centrifugals operated at relatively low speeds and producing relatively low pressures. Maximum advantage was taken of existing openings in reducing the amount of excavation required for each installation, and the layouts are therefore quite diverse. Fan stations and connections are of ample size and, except for the main exhaust fan on No. 9 level, have very little traffic on adjoining openings, which are protected by single doors only. The discharge side of the main exhaust fan is a rather busy supply station on what amounts to a minor shaft, the Dull raise, and is protected by an air-lock. The fans discharge through tight concrete and wood bulkheads, to which they are connected by short sheet-iron ducts.

The main supply fan at the top of the main air raise on No. 10 level is a No. 12 Sirocco operated at 198 r.p.m. by belt drive from a 40-hp., 2200-volt, 60-cycle, 3-phase, 875-r.p.m. induction motor. It was handling 33,000 c.f.m. of air having a density of 0.0695 pound per cubic foot with a static pressure difference of 1.1 inches water on the tight bulkhead. About 2,000 c.f.m. of the total was return-air leakage through a single door on a connection to the No. 1 shaft. The fan is installed on a short crosscut and discharges directly into the top of a 40° inclined raise.

The booster fan at the bottom of the main air raise on No. 16 level is a No. 9 Sirocco operated at 240 r.p.m. by "Texrope" drive from a 25-hp., 440-volt, 870 r.p.m. induction motor. It is installed in a short crosscut off the bottom of the air raise and discharges through a fairly tight bulkhead in which there is a light wooden door for entrance to the fan chamber. The fan was discharging about 31,000 c.f.m. through the crosscut and handling possibly an additional 3,000 c.f.m. leakage through the bulkhead. The static pressure difference on the latter was 0.90 inch water and the air density 0.717 pound per cubic foot.

The booster fan on No. 10 level near No. 2 shaft is a No. 10 Sirocco operated at 194 r.p.m. by belt drive from a 20-hp., 2200-volt, 870-r.p.m. induction motor. It is installed in the main drift and discharges through a tight concrete bulkhead. The fan was handling about 40,000 c.f.m., including 1,000 c.f.m. leakage through a single door on a run-around drift and crosscut, with a static pressure difference on the bulkhead of 0.4 inch water at an air-density of 0.0670 pound per cubic foot.

The main exhaust fan on No. 9 level at the foot of the Dull raise is also a No. 10 Sirocco, operated at 327 r.p.m. by belt drive from a 50-hp., 2200-volt, 870-r.p.m. induction motor. It is installed in a run-around off the main haulage drift at the rear of the raise station, into which it discharges through a tight board brattice. The fan was handling about 55,000 c.f.m. with a static pressure difference of 1.90 inches of water on the bulkhead at an air density of 0.0675 pound per cubic foot. A 6 by 7 foot timbered drift on the intake side of the fan is separated from the adjoining intake haulageway by a single door on a short connection through which 2,500 c.f.m. leakage was entering. It is also connected to a caved stope through which 7,000 c.f.m. of the return air was being recirculated, and is connected with the top of a 45°, 5 by 7 foot raise joining No. 2 shaft 60 feet below the collar. The collar of the shaft is open to the passing intake-air current, but the short-circuit of intake air was limited to about 6,500 c.f.m. by the action of the No. 10 level booster fan, which was also effective in making the No. 2 shaft neutral below the No. 10 level. An air-lock in a concrete-lined crosscut, separating the fan discharge from the passing intake current, was leaking to the extent of 4,000 c.f.m. A small plate suspended in the fan dis-

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charge current is equipped with electrical contacts that close a circuit on a bell which notifies the hoistman on No. 1 shaft when the fan stops.

Comparison of these fan performances with manufacturer's data indicates that the fans were operating against resistance conditions varying from one-half to twice that for which they were designed but at efficiencies only 4 to 6 per cent under maximum efficiencies.

Condition and Dimensions of Airways

The major operating openings, such as the Kellogg tunnel, the No. 9-level haulageway, the main shafts and the main crosscuts from the shafts to ore zones, are relatively large and regular, but are used only as minor airways. Volumes of flow are limited to a large extent by the main downcast air raise and the main intake drift on No. 10 level, where the average clear sectional areas are about 35 to 40 square feet in timbered or rough rock airways, and are limited by the outlet connections near the main exhaust fan, where the areas also range from about 35 to 40 square feet; both of these main airway sections are quite irregular as to direction of flow and, to some extent, are obstructed.

The 10,000-foot Kellogg tunnel, and its continuation as a main haulageway to the shafts, has an average cross section of about 8 by 9 feet in both timbered and rock sections, with several large radius bends joining long straight sections. At the intersection of the tunnel and main haulageway, a 50-square-foot inclined rock raise extends to the No. 10 level west end intake drift. The cross-sectional area of the ore cars is only 16 square feet, and trips do not materially affect the air flow through the tunnel.

The No. 1 shaft slopes 50° and is open-timbered, with two 5 by 5.5 foot skipways and an obstructed 5 by 5.5 foot pipeway and manway compartment; the latter has a 3 by 5 foot clear area. The No. 2 shaft is an open-timbered shaft sloping 40.5° with two 4.6 by 5 foot cage compartments and a manway with a clear area about 3 by 4.5 feet. Both cages and skips have good clearance, and do not affect the total flows appreciably.

The Dull raise has a 4 by 5 foot cageway and a 3.5 by 4.5 manway. This raise is through heavy ground and is heavily timbered. The Cherry and other raises are of about the same dimensions.

Main crosscuts off the shafts are mostly straight unlined crosscuts having an average section about 8 by 8 feet. Drift openings are very irregular, the average condition being a 30 to 35 square-foot heavily timbered opening.

Stope manways are solid-cribbed 3 by 4 foot openings, without platforms, carried up through the fill on 50-foot centers. The cribbing is 6-inch half-round material with the rounded side in. Many of the manways are crushed and abandoned before the stope is completed but enough are maintained for ventilation.

Three-compartment timbered raises are put through on the footwall from about the center of each stope to the level above. These have a 3 by 6 foot chute, a 3 by 6 foot timber slide, and a 2 by 6 foot open manway. After the stope is halfway up, this raise becomes the main passage for men and supplies and, in long stopes and under certain conditions of mining, is supplemented by one or more additional raises of the same type driven up from the back of the stope along the footwall.

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followed by fill, which leaves a narrow staggered vertical opening about two sets (6 feet centers) wide and up to seven or eight floors high.

A large number of doors are in use for distributing the air currents. No standard design is used, but the majority conform closely to a general type of single door which has a 4.5 by 6.0 foot opening. The door is made of two plies of 1-inch material, one horizontal and the other vertical, set in a jamb and hung from a vertical frame of heavy timber by two or more standard 12-inch strap hinges. The opening between frame and rock is filled with a mud of fine wet gouge between boards nailed to the frame, and, under the damp to wet conditions prevailing, makes a very tight seal. Few doors are provided with sill blocks, but belting is occasionally used to reduce leakage on the higher-pressure doors. Air pressure is relied on to keep doors closed, and few doors have counterweights. On active haulageways, red lights are placed on each side of a door as a warning of its position to motormen.

Doors are invariably used singly rather than in pairs to form air locks, and pressures on them are rarely over 0.3 inch. No mechanically-operated doors are used. A compressed-air operated door, of the type common in Arizona mines, was tried on one level but was abandoned as requiring too much attention to keep in good operating condition. A large proportion of spring and warped doors was noted, ascribed to the use of the jamb and of short hinges.

Auxiliary Ventilation

Very little auxiliary ventilation is required and but two units were operating in May, 1930. One was a small Sirocco, Type P, high-pressure blower, direct-connected to a 15-hp., 110-volt, 1760 r.p.m., d.c. motor, taking air through a 20-inch galvanized-iron pipe from the main return current on the No. 10 level and discharging it through a long 12-inch canvas tubing to an exceptionally hot small stope on this level, where the oxidation of pyrite in a crushed zone produces local high-temperature conditions.

The other was a No. 6½ Buffalo Forge blower, direct-driven at 720 r.p.m. by a 5-hp., 220-volt d.c. motor, taking air from a crosscut through a short length of 12-inch galvanized-iron pipe and discharging it through a short length of 16-inch pipe to provide air for the engineers on the No. 9 shaft station.

Several other small electrically-driven units of various types are said to be on hand and have been used as exhaust units with small-diameter galvanized-iron pipe in the initial development of each lowest level where long dead-ends are involved. Sinking of a 300-foot winze off the bottom level was being accomplished without auxiliary ventilation.

In the winze and in a number of stopes, compressed air is blown for air-motion cooling effect, particularly at points where drills are not operating. Drill exhausts provide comfortable air conditions in lowest-level drifts and crosscuts.

Natural Draft

The natural drafts exerted on the mine air flow are a combination of those due to air columns both inside and outside the mine, the latter acting through about 1,400 feet and

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the former through about 3,200 feet. On account of the slow air movement through the upper intake openings, surface temperatures have only a minor effect on the natural draft pressures that are generated within the mine by temperature differences between the downcast and upcast circuits, and that act in series with the fan pressures. For these inside columns, the conditions noted in May, 1930, indicate a total natural draft, from surface to the No. 19 level, of approximately 1 inch, which is probably a quite constant value. The outside 1,400-foot column acts only through the Kellogg tunnel and mainly in conjunction with the column in the Last Chance intake openings. These workings are said to be downcast throughout the year, but volumes are dependent on draft conditions in the Kellogg tunnel. The latter is a strong intake during the winter and supplies almost as much air as the intake system can handle, thereby reducing the intake through the Last Chance workings and, at times, that through the east-end Sullivan workings. When the draft is outcast in the tunnel, the additional air is pulled down through the Last Chance workings.

A few observations made over a period of a week in May, 1930, indicated that the probable maximum intake at this season was about 15,000 c.f.m. on cool (40° F.) nights and up to 8,000 c.f.m. outflow on warm (76°) afternoons, with the change point roughly at 65°. Before the mine was mechanically ventilated, the change point is said to have been at about 56°, the difference being due to the constant inward pull of the fan system on the tunnel as an intake.

Various manifestations of natural draft effects occur in the workings, as for instance on the east side where a chain of stopes in ground that averages cooler than the upcast air in the shafts is ventilated by a small downcast current with very little flow out through crosscuts open to the shafts except on the lowest (No. 19) level.

Air Conditions

Air Temperatures.- Although all workings above the tunnel level and large sections of the mine below this level have quite comfortable working conditions, the general condition off the main air currents below the tunnel level is somewhat uncomfortable due to high temperatures caused on lowest levels by rock temperatures, and on intermediate levels by air moving slowly through openings in filled stopes in which it is heated, probably by oxidation of iron carbonate in the fill and by timber decay, and in one stope on No. 10 level locally by oxidation of pyrite in crushed ground. Active workings are so far underground and the intake air currents course at such low velocities that temperatures in active workings are not affected by seasonal fluctuations of surface temperatures. Due to naturally wet conditions, air currents are practically saturated throughout the mine, and due to the numerous large openings, there is very little cooling due to air motion. Foggy zones are of quite frequent occurrence.

Air temperatures are 77° on the lowest (No. 19) level, close to 75° in the lower stopes, and close to 80° in a few upper stopes; relative humidities range from 95 to 100 per cent. The downcast air enters the No. 16 level at 67° but rapidly warms up as it travels through stopes above and below this level and increases to maximums of 83 and 84° where the returns emerge on the No. 10 level. Temperatures of the upcast currents in the main shafts are within a degree or two of 75° throughout and the air is saturated or practically so.

One small fan-pipe ventilated stope off the No. 10 level, locally known as the "hot box," had air temperatures on the mining floor of 85° wet bulb and 95° dry bulb; and in the unventilated top floor, two sets above, the temperatures were 108° wet bulb and 112°

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dry bulb. This stope represents a special condition of oxidizing pyrite in crushed ground.

Above the tunnel level, the average condition in isolated active workings is about 50 to 60° on the intake side and 70° in the exhaust section, although temperatures vary over a wide range and are often uncomfortably cold. The lowest temperature noted was 42° with the surface air at 50°. Some of the main downcast currents were entering the tunnel (No. 9) level, in May, 1930, at temperatures as low as 53 to 56°.

Rock Temperatures.- A few determinations of rock temperatures in 5-foot holes made when advancing faces in virgin ground on the Nos. 6, 17, and 19 levels, showed a range of from 63.0° on the No. 6 level to 77.2° on the No. 19 level (4,200 feet below surface of mountain) and indicate a rock-temperature gradient of 180 feet per 1°, which is a very low gradient and somewhat lower than those determined in the Morning and Hecla mines.

Air Quality.- The analyses and pertinent data regarding six air samples taken during this survey are shown in Table 1. They show a rather surprising state of affairs with respect to high carbon dioxide and low oxygen content of the intake air. Previous sampling of the intake air on No. 10 level by the company in 1923 and 1924, had shown but 0.3 to 0.4 per cent carbon dioxide and but 0.1 to 0.2 per cent oxygen depletion, attributed to downcasting the intake through an old but active stope above No. 10 level which has since been partly shut off. The purity of the Sullivan side intake had never been questioned, as there is but little travel through stopes on this side, little timber decay and very little siderite in the gobs. Previous sampling had been done, however, at times when the Kellogg tunnel was a major intake and the Last Chance workings a minor intake, which are the normal conditions throughout somewhat more than one-half of the year. During the summer months, the Last Chance workings become a major intake and the Kellogg Tunnel a very minor intake, which were the conditions when these samples were taken. Action analogous to that taking place on the intakes is indicated throughout the mine, resulting in a general air supply that is exceptionally high in carbon dioxide and low in oxygen. The departures from normal surface air proportions (20.93 oxygen and 0.03 carbon dioxide) are, however, not considered detrimental to health by physiologists, but the effect on labor efficiency is due to the more rapid breathing caused by the excess carbon dioxide; 0.5 per cent is said to result in a slight increase in the rate of breathing and 2.0 per cent in an increase of about 50 per cent.

While the approximately equal values of CO_2 excess and O_2 depletion indicate timber decay as the probable cause of the excessive air vitiation, the amounts are larger than those usually definitely attributed to such a cause and are probably due partly to oxidation of the siderite in the ore gangue. It is definitely known that siderite is much more abundant on the Last Chance side than on the Sullivan side, and the air samples show corresponding analyses.

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Table 1. - Analyses of mine-air samples, Bunker Hill and Sullivan mine
May 15-20, 1930

Location and description	Wet bulb, °F.	Dry bulb, °F.	Volume, c.f.m.	Chemical analyses CO_2	O_2	N_2	CO	CH_4
Intake air on Sullivan side on No. 9 level	55.0	56.0	23,000	0.40	20.53	79.07	0.00	0.00
Intake air at inlet of main supply fan	61.0	62.0	33,000	1.10	19.94	78.96	.00	.00
Face of 300-foot winze off No. 19 level - mucking	76.5	76.5	Comp. air only	.16	20.67	79.17	.00	.00
9th floor above No. 18 level in Back Mac stope	78.0	78.0	3,000	.97	20.04	78.99	.00	.00
No. 14 level - West Eck drift at No. 11 chute	70.0	71.0	3,000	1.23	19.85	78.92	.00	.00
Return air at fan discharge on No. 10 level, No. 2 shaft	82.0	83.5	39,000	1.82	19.02	79.16	.00	.00

Ventilation Costs

All ventilation expenditures are charged direct to a ventilation account, the distribution of which as to power, labor, and supplies is not a matter of record. Costs include all fan installations and main air raises, but do not contain a charge for compressed air used for ventilation. Totals for the last five years are given in Table 2, and include the cost of three sections of the main air raise and one main fan installation.

Table 2. - Ventilation costs, Bunker Hill and Sullivan Mine

Year	Total cost	Unit costs in cents per Ton of ore	Lb. of lead
1925	$15,119	3.3	-
1926	9,158	2.0	-
1927	10,090	2.2	-
1928	9,631	2.1	-
1929	14,282	3.2	-
Mean	$11,656	2.6	-

Under present conditions, ventilating air costs about 0.00006 cent per cubic foot. The four main fans use approximately 80 hp., equivalent to about 0.06 hp. per ton of production, and produce about 500 c.f.m. of ventilating air per horsepower. Records for April, 1930, show that approximately 24 per cent of the electrical power used for mining operations, exclusive of air compression, is required by the ventilating system.

MORNING MINE

The Morning mine of the Federal Mining and Smelting Co. is operated through a 10,000-foot crosscut tunnel entering the north side of the mountain at an elevation of 3310 feet, just west of the town of Mullan. Vein outcrops on the mountain reach an altitude of 5,680 feet, with the adit drifts of earlier operations off the side of a large gulch. The

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tunnel, known as the 800 level, is practically the top of the present mine, although there is some company work and some leasing above this level. The lowest opening was at the 3650 level in April, 1930, at an elevation of 460 feet.

Although three veins have been developed, present operations are on the Morning vein only, a lead-silver-zinc fissure vein 6 to 30 feet wide and averaging 13 feet, which strikes about N. 65° W. and varies in dip from 80° NE. to vertical. The vein is in a quartzite formation and in a zone of close sheeting that develops heavy side pressure upon weathering. The ore occurs as stringers and bunches of fine-grained galena which is intimately mixed with sphalerite on the west side. Gangue minerals are quartz, barite, and siderite. The productive ore zone is from 1,500 to 2,000 feet long on active levels.

In April, 1930, company and leasing operations were producing about 1,100 tons a day of ore averaging 9.1 per cent lead, 6.0 per cent zinc, and 3.5 ounces of silver per ton, of which about one-quarter was contributed by leasers. Company underground men on two shifts totaled 380, of which 235 were on the day shift. Leasers were working only one shift and totaled about 70, of whom 55 were on or below the tunnel level.

Mine Openings

Levels are driven at 200-foot vertical intervals off the main shaft, sunk from the 10,000-foot No. 6 crosscut tunnel on the 800 level, with one 250-foot lift from the 800 to 1050 levels. Level numbers are designated by the vertical distance below the No. 5 adit tunnel, which is 1,570 feet below the highest outcrop and connected to the No. 6 level by a separate inside (New) shaft. Above No. 5 tunnel level are a number of other open tunnel levels connected to No. 5 by a series of raises.

The main shaft is 110 feet in the footwall and is connected to the vein on each level by two parallel crosscuts from opposite sides of the shaft. It has four compartments and handles all ore, men, and supplies below the main tunnel level.

A two-compartment stull raise is carried up along the east side of the ore body as a main air raise, and similar raises connect the lower levels on the west side. These are composed of 45° sections extending from and returning to the level drifts.

Mining Methods

All of the mining is by a stull set and fill method with horizontal openings and breast mining. Stopes are timbered with heavy drift sets on 5-foot centers carried up in a similar way to square-sets. Caps average about 2 feet in diameter, are the full width of the vein--usually 8 to 16 feet--and are blocked tightly to the walls, with at least 18 inches of blocking on each end, locally termed "heading." Three-compartment raises are carried up on 125-foot centers just ahead of the stoping and comprise a chute, timber slide, and manway with large clear openings. Tram cars are used for ore and waste, and at least three floors are open at a time for mining, mucking, and tramming, respectively. Although all sections between raises do not progress uniformly, the stopes have a continuous opening from shaft pillar to ore limits and on account of the difficulty of maintaining raises are carried up as dead ends with respect to ventilation currents, which are coursed through the drifts and through rock raises at or near the ends of the levels.

In April, 1930, company operations were practically confined to stopes between the

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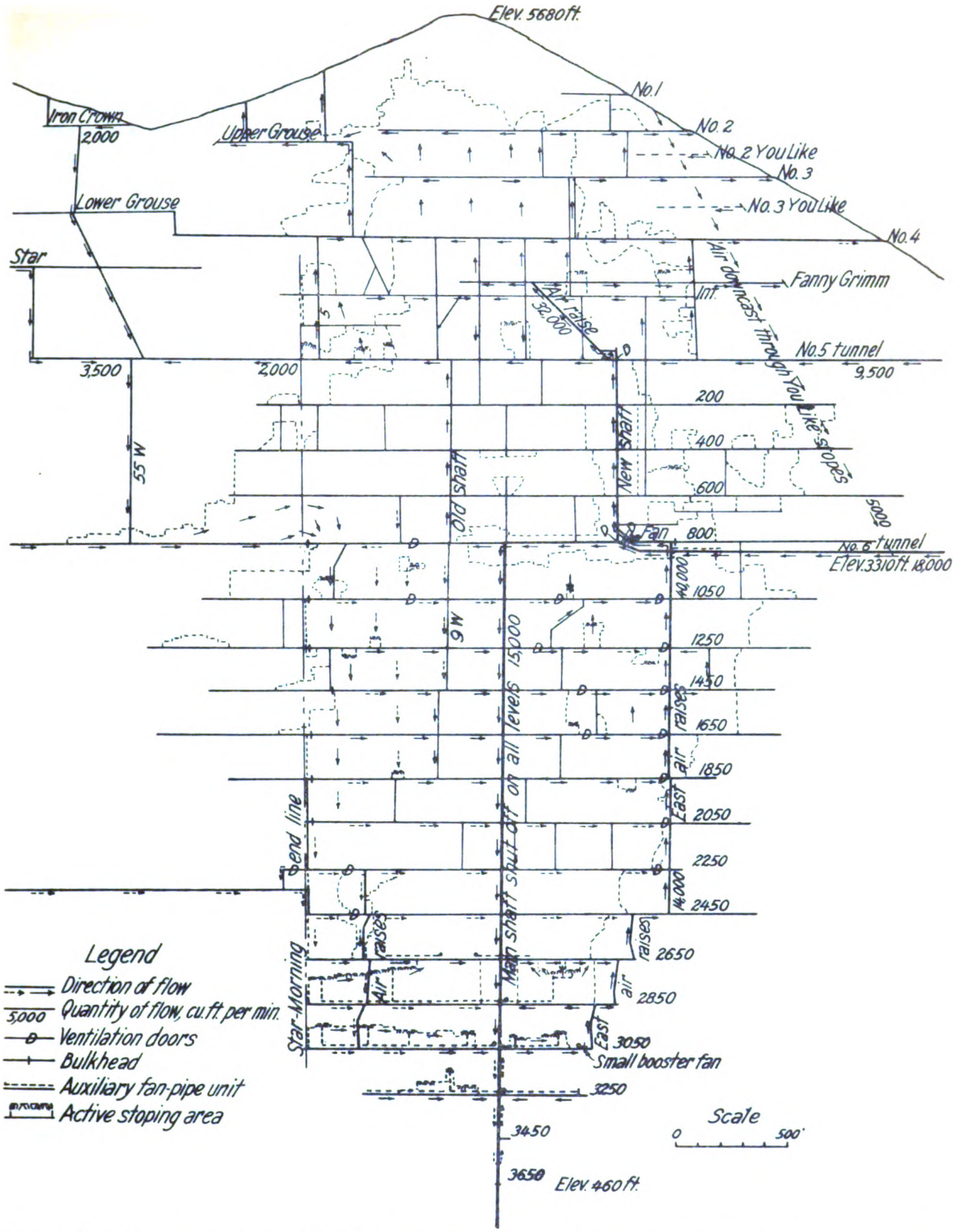

Figure 2.-Diagrammatic vertical section showing ventilation system of the Morning Mine
May. 1930

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2650 and 3250 levels, although a few small stopes were being operated between the No. 6 and No. 5 tunnels and one was opened just above the latter. Scattered leasing operations on small stringers off the main vein were in progress from the 1850 level to the No. 4 tunnel level. A large block of old workings between the 1850 and 2650 levels was temporarily idle but will probably be opened to leasers eventually. Considering a 125-foot stope section as a complete stope, company operations were equivalent to 14 stopes; and development work comprised 4 drifts or crosscuts and 1 raise.

Ventilation History

The mine is mechanically ventilated by an underground fan and was the first mine in the district so ventilated. The active zone is 4,000 to 5,000 feet underground in warm rock, and the ventilation system was installed to improve comfort conditions as to temperatures and air motion.

Air conditions in working places gradually became uncomfortable as the workings gained in depth; and natural draft, because of the relatively few openings available for flow, was unable to produce comfortable working conditions. The first fan was a No. 7 Sirocco, installed in February, 1918, at the collar of the present east-side raise system, taking air from the No. 6 tunnel and You-Like workings and blowing it down the raise to the 1850 (lowest) level with return up the main shaft and to surface through old workings. The results were not entirely satisfactory, so that during 1919 this fan was moved to an exhaust position near the shaft top, and the present No. 8 Sirocco was installed to blow down the air raise. During the summer of 1925 the direction of flow was reversed by changing the fan on the air raise around to exhaust from the raise, thus making the main shaft downcast. Although mainly designed for general improvement of conditions, particularly in the shaft, the change was also a safety measure and arrangements were made for reversing the flow in case of necessity. Since that time only minor changes have been made in the system, except that in 1929 additional outlet capacity was considered necessary and a large inclined air raise was driven from the No. 5 tunnel level to the Fanny Grimm level 300 feet above it.

A few small auxiliary fan-pipe units were used for special conditions from about 1916 to about 1925. At this time the stopes, operated as separate dead-ended sections, were somewhat warm and gassy, and fan-pipe ventilation of stopes was started and gradually developed through succeeding years. About 1927 a change was made to continuous-back stopes, which resulted in improved circulations and clear air, although the stopes remained warm. More and larger auxiliary units have since been installed.

Distribution of Air Currents

The major elements of the distribution system, as determined by a brief survey in April, 1930, are shown on the vertical projection of the mine workings (fig. 2). The main air supply intakes through the long No. 6 tunnel and connected abandoned workings above it on the You-Like vein, downcasts through the main shaft, and is drawn from the shaft by fans of auxiliary fan-pipe units and blown into the stopes. From the stopes it passes on open levels to a return-raise system connected to old upper workings that have numerous surface outlets. The main fan is installed on the return-raise system at the east end of the ore zone on the 800 level.

In addition to the main intake, there are small intakes from the adjoining Star mine, both from the Hecla mine by way of the Star crosscut and from surface openings, and

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through the No. 5 tunnel. Air from the former circulates through the leasing operations below the 800 level and enters the return raise as leakage. The No. 5 tunnel intake air passes through this level and upcasts by natural draft to surface outlets.

High-speed movement of trains of large cars in the relatively small (6.5 by 7.5 ft.) haulage tunnel causes large variations in the quantity of flow on this major intake which are compensated for by variations in the other intakes, particularly the intake through the You-Like stopes, to such an extent that although the variations in the flow ranged 5,000 cubic feet per minute above or below the normal of about 18,000 c.f.m., the quantity handled by the main fan varied but 500 c.f.m. from the normal of 40,000 c.f.m. Recirculation of return-air leakages above the 800 level are somewhat larger than the returns that are independent of the fan circulation. The total air supply to the mine, including about 4,000 c.f.m. of compressed air liberated below the 800 level, is estimated as approximately 40,000 c.f.m., equivalent to about 170 c.f.m. per company man underground on the day shift, or about 130 c.f.m. per man, including leasers.

Of the total circulation, about 15,000 c.f.m. was downcasting through the main shaft to the active stoping zone, leakages at doors on the shaft crosscuts being practically negligible because of low pressures in both directions. The shaft, in fact, was shut off by doors on all levels and acted as a pressure chamber from which the small auxiliary fans on lower levels were drawing their supply. The necessity for this mode of ventilation, aside from the method of operating stopes as dead ends, and other major difficulties that have been experienced in ventilating the mine arise from the difficulty of maintaining effective seals in stoped ground where the raises and chute openings were not filled and are now caved. The return raise system is connected to stoped ground on a number of levels and the west sideline connections to the Star mine are in similar ground. Multiple doors and brattices on the drifts, both at the air raise and on the Star mine connections, have not proved effective in improving the ventilation of lower levels on account of large intakes to the return-air raise on upper levels. Small booster fans on lower levels of the air-raise have also proved ineffective to a large extent. The return-air raise is naturally a high-resistance airway and the practicable inability to hold high pressures through the upper levels below 800 has seriously handicapped the ventilation of the lower levels, which are handicapped also by the method of dead-end stoping considered necessary.

Air velocities on the exceptionally large drifts are practically negligible in active zones, and an attempt is made to increase comfort in these zones by air motion supplied by compressed-air operated Venturi injection blowers attached to short lengths of canvas tubing.

The mine makes a considerable amount of water and is damp practically throughout.

Performance of Main Fan

The main fan is a No. 8 double-inlet, single-width American (forward-curved-blade) Sirocco centrifugal fan, operated at 600 r.p.m. by belt drive from a 100-hp., 2200-volt, 60-cycle, 3-phase, 880-r.p.m. induction motor. The fan is installed on the 800 drift just east of the intersection of the No. 6 tunnel, which continues through the vein 150 feet to the New shaft extending from this level to No. 5 tunnel level in the hanging wall. The rock drift connection to the main shaft is in the footwall. The fan draws air from the main air raise through a short drift connection and discharges it through a short crosscut and inclined raise to a bratticed-off compartment of the New shaft. It was handling about 40,000

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c.f.m. of air weighing 0.0640 pound per cubic foot with a static pressure in the discharge duct of 5.05 inches water. Manufacturer's data indicate that the fan was operating within about 1 per cent of maximum efficiency.

Entrance to the fan room is from the No. 6 tunnel and is protected by a very tight air lock. A split duct on the discharge and doors on the airways provide an arrangement whereby the direction of flow can be reversed below the 800 level without reversing the main tunnel intake. The fan installation is in heavy ground. Just before this survey the fan foundations had settled to the point where the fan speed was reduced to 546 r.p.m. through lack of alignment of bearings.

Condition and Dimensions of Airways

The major operating openings (such as No. 6 and No. 5 tunnels, the main shaft and connecting rock drift, shaft crosscuts, and main drifts) are relatively large and regular, but are used only as minor airways. Drifts in active zones are exceptionally large, and to facilitate repairs the first stope floor is left open. Volumes of flow are limited to a large extent by the east-side main upcast-raise system below the 800 level. This is composed of two-compartment 45° raise sections in the hanging wall alternating with vertical raise sections in the vein and includes a number of drift offsets. Total clear areas on this raise system are mostly between 35 and 40 square feet. At this time, there were also numerous constrictions at bends and by chute mouths at drifts which, however, were in process of elimination. A similar 45° "dog-leg" raise system of hanging-wall raises extends from the 3050 to the 2250 level on the west side, but is at present only a very minor airway. The upcast compartment of the New shaft from No. 6 to No. 5 tunnel, 800 feet, also limits the flow, for although it is smooth-lined, it has an area of but 16 square feet.

The 10,000-foot No. 6 tunnel has average cross sections of 6.5 by 7.5 feet in timbered sections and 8 by 8 feet in rock sections, with the latter size predominating. It is composed of two straight sections joined by a large-radius curve. The ore and waste cars used in this tunnel have a total cross-sectional measurement of about 16 square feet.

The main shaft is a vertical, open-timbered, four-compartment shaft with two 4.5 by 5.0 foot skip compartments, a service cage compartment of the same size and an obstructed 3.5 by 5.0 foot manway and pipe compartment. The cage compartment is divided from the adjoining skip compartment by a plank brattice centered on the timbers. Skips and cages have small clearances and affect the air flow to some extent, but not seriously.

On the lower active levels, two parallel 7 by 8 foot rock crosscuts, averaging 110 feet long and on 100-foot centers, connect the shaft stations with the drifts. The latter are exceptionally large, usually 8 by 9 feet inside timbers, and have an open stope floor above them. Upper levels, now given over to leasing, have but one crosscut from shaft to the vein, and drifts on the latter are quite small, irregular, and heavily timbered.

Manways and timber slides occupy but part of the width of the vein in large openings at 125-foot centers, which are roughly floored over at each set, but not filled until necessary. On completion of a stope, however, all openings are filled instead of allowing raise openings to cave eventually, as is the more common practice in filled-stope mining. Openings in the stopes are large as respects air flow, since the minimum opening is three 9-foot floors.

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Doors and Bulkheads

The ventilating system requires a large number of doors for distributing the air currents, and a number are installed for emergency use in case of fire. The general design for ventilation is a double door closing against a heavy, vertical, timber frame having a 4.5 by 6.2 foot opening and sealed to the rock walls with board framing caulked with rags and oakum. The two sections of the door are made of two plies of 1-inch board, with the plies horizontal and vertical, and are heavily braced on the side opposite the hinges with mortised 1½ by 6 inch boards which extend around the perimeters, across the width on the lines of the heavy strap bar hinges, and diagonally from the upper inner side to the lower outer side. One section carries a cleat on the junction side and is counterweighted. Good wooden sill blocks are provided, and in particular cases canvas flaps are used to reduce leakage. Contrary to general practice, the door sections are painted; this is done on the surface before they are sent underground. With few exceptions, doors are used singly rather than in pairs to form air locks, and all are operated by hand.

A few single doors are in use; but the double type is preferred as resulting in lower maintenance charges and less leakage. Concrete frames have been tried in a few places, but were crushed by ground movement.

All surface openings are provided with doors, as are open connections to the Star mine. One at the portal of No. 6 tunnel and two on the rock drift connecting the tunnel with the main shaft are of a particularly rugged design, embracing double iron-plate doors closing against a channel iron frame set in a concrete bulkhead and having openings of about 6.0 by 7.0 feet. On the 2250 level escapeway connection to the Star mine, two large single wooden doors covered with galvanized iron are hung on opposite sides of the same frame. The frame is made of channel irons set in a concrete bulkhead, and the doors are provided with latches.

A number of bulkheads are used to shut off caved openings. These usually consist of 2-inch planking cleated with similar material and caulked with rags or oakum.

Auxiliary Ventilation

Although a few fan-pipe units were used earlier for special local conditions, their real use in the active stoping zone started in 1925 when four No. 175 SM Vano (high-speed electrically-driven propeller) type Coppus fans were put in service with 12-inch canvas tubing. This type became standard, except that larger sizes of both fan and tubing have been gradually put in service and the smaller sizes discarded.

In April, 1930, the auxiliary units of this type in service included one No. 300 with 2.5-hp. motor, three No. 350 with 5-hp. motors, and two No. 425 with 15-hp. motors. Three of these and a No. 4 Sirocco (15-hp. motor) were installed on closed-off shaft stations blowing through 20-inch canvas tubing to the drift and, through two 16-inch branches, to east and west side stopes. Two were mounted in the 2650 drift to provide local air movement through 16-inch tubing. One was installed as a booster on the bottom of the upcast air raise, blowing through a door on the drift. Local ventilation of the main hoist room was provided by a No. 7 Buffalo Forge fan, direct-driven by a 10-hp. motor at 1750 r.p.m., exhausting air from the room through 16-inch galvanized-iron pipe and discharging it to the foot of a naturally upcast raise (Old shaft) through 12-inch pipe.

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Local air movement on the large drifts in the active stoping area was being provided by six venturi-shaped compressed-air injectors discharging through short runs of 16-inch canvas tubing. The design follows that used in the United Verde mine. The venturi section is made of galvanized iron, is about 8 feet long, has a maximum diameter at each end of 16 inches and a throat diameter of 8 inches, and uses a 1/4-inch nozzle on the compressed-air pipe. An approximate average performance of these units was 2,000 c.f.m. through 100 feet of fairly straight 16-inch canvas, with the discharge end constricted to about 12-inch diameter, at a static pressure (0.07 air density) of 1 1/4 inch. The larger auxiliary units were delivering 3,000 to 12,000 c.f.m. at static pressures of 4.0 to 1.0 inch water.

Local air movement, at a number of working places in the lower levels, is supplied by blowing compressed air directly from the pipes. Compressed-air is also used for blowing out development faces after blasting, for directing smoke produced by emergency blasting during the shift, and in the venturi injectors. The compressed air, on account of long travel through cold ground before it reaches the mine, is exceptionally cool at underground points, sometimes reaching a temperature as low as 10° below rock temperatures, and thus reducing the temperature other than by air motion, which is most often the only factor involved.

Natural Draft

The total height of the natural draft column is approximately 4,000 feet, No. 2 tunnel to the 3050 level, with a surface-air component of about 1,700 feet. The columns below the 800 main tunnel level create but negligible pressures on account of the difference of only 2 or 3° in average temperature conditions between downcast and upcast columns. Above the 800 level, natural drafts are quite important but act with the fan circuit, except during exceptionally warm days in summer, due to the rather warm column of upcast air in the upper levels. In April, 1930, both the No. 5 and No. 6 tunnels were natural intakes with the fan down, the flow through the latter under this condition being about 10,000 c.f.m.

Air Conditions

Air Temperatures.- Throughout the leasing zone of operations, that is, throughout all of the workings above the active stoping zone, air conditions are very comfortable, although the air is foggy in many places. The active zone, 2650 to 3450 levels, is in moderately high-temperature rock 4,200 to 5,000 feet vertically below the top of the mountain, and air conditions are uncomfortably warm throughout this zone. Here the air temperatures range from 78 to 83° with corresponding relative humidities varying from 96 to 100 per cent. The lowest temperatures—78 to 79°—were found at the three advancing faces of the lowest active level, the 3450, which at this time was a dead-ended level off the shaft ventilated entirely by compressed air. With a high velocity, these temperature and humidity conditions are made fairly comfortable, but the general condition is quite uncomfortable and inducive to copious perspiration. Most of the miners work in their undershirts and a few strip to the waist.

The workings are damp to wet throughout, and all miners provide themselves with heavy coats for the 15-minute ride through the No. 6 intake tunnel to surface. Covered coaches are provided for the lower level men.

Due to the long travel of the intake air, inside temperatures are practically constant throughout the year, and the temperature at the collar of the downcast shaft, including

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a 3° rise due to an adjacent compressor room, is practically constant at 69° wet bulb, 70° dry bulb.

Rock Temperatures.- Rock temperature determinations in 5-foot holes in development faces on virgin ground showed 80.5° on the 2450 level and 87.2° on the 3450 level (5,000 feet below the surface), indicating a gradient of approximately 1° in 150 feet increase in depth.

Air Quality.- Analyses and pertinent data regarding six air-samples taken during this survey are shown in Table 3. They show air of sufficiently good quality to have no appreciable physiological effects. The rather rapid rise in carbon-dioxide content of the return air through old stopes indicates a similar action, but on a smaller scale, to that taking place in the Bunker Hill and Sullivan mine, and in this case is probably attributable about equally to timber decay and chemical reactions of air and moisture with siderite in the gobs. Part of the intake is through old workings and the air undoubtedly is similarly affected, with the result that both carbon-dioxide excess and oxygen deficiency are somewhat larger than for the average mechanically ventilated metal mine.

Ventilation Costs

Operating costs are charged to a separate ventilation account and are distributed as to labor, power, and supplies. New equipment and its installation, including both primary and auxiliary fans, are charged to an equipment account and ventilation raises are charged to a development account. Through the courtesy of the company officials, ventilation costs have been segregated from the latter two accounts and total and unit costs are presented in Table 4 for the five-year period 1925-1929. No compressed-air is charged to ventilation.

Table 3. - Analyses of mine air-samples, Morning mine, April 25 - May 3, 1930

Location and description	Wet bulb, °F.	Dry bulb, °F.	Volume, c.f.m.	Chemical Analyses CO_2	O_2	N_2	CO	CH_4
South face of west cross-cut off shaft, 3450 level	78.0	78.5	Drill-exhaust only	0.20	20.72	79.08	0.00	0.00
Face of 3250 west drift at No. 23 chute	82.0	82.2	Fan-pipe ventilation	.32	20.51	79.17	.00	.00
Eleventh floor of 3050 west stope at No. 28 chute	79.5	81.0	Comp. air only	.32	20.49	79.17	.00	.00
Seventeenth floor at east end of 2650 east stope	81 0	81.5	Very small	.30	20.62	79.08	.00	.00
Main return air current in air raise below 1450 level	78.0	78.0	17,500	.51	20 44	79.05	.00	.00
Total return air current at fan inlet on 800 level	76.0	76.3	34,500	.74	20.12	79.14	.00	.00

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Table 4. - Ventilation costs, Morning Mine

Year	Operating costs				Unit costs in cents per			
	Labor	Power	Supplies	Total	Ton of ore	Lb. of lead	Lb. of zinc	Lb. of metal
1925	$4,809	$6,975	$1,982	$13,766	4.6	0.021	0.073	.017
1926	4,573	5,256	1,333	11,162	3.7	.016	.040	.011
1927	5,356	4,450	2,311	12,117	4.4	.018	.038	.012
1928	6,412	4,735	4,223	15,370	5.6	.023	.042	.015
1929	6,923	4,667	4,058	15,648	5.6	.024	.039	.015
			Total operating	$68,063				
			Total for equipment	6,776				
Total for ventilation raises				30,361				
Grand total for 5-yr. period				$105,200				
Mean per year for 5-yr. period				21,040	7.4	.031	.071	.022

Under present conditions, ventilating air costs about 0.00011 cent per cubic foot. The ventilating system uses about 130 continuous horsepower, or 0.12 hp. per ton of production. The main fan uses about 70 hp. and produces about 570 c.f.m. per horsepower. Records for the early months of 1930 show that approximately 22 per cent of the electrical power used for mining operations, exclusive of air compression, is required by the ventilating system.

HECLA MINE

The Hecla mine of the Hecla Mining Co. is operated through a vertical shaft in the canyon of Canyon Creek at Burke, at the foot of a steep mountain. The shaft collar is at an elevation of 3,780 feet. Original development was through an adit tunnel, No. 3, which is close by and 30 feet lower. The uppermost opening, a raise driven to surface from a separate ore body east of the main Hecla lode, is at an elevation of 5,280 feet and the lowest openings are on the 2800 level, elevation 980 feet, off an interior winze which is now (April, 1930) being connected to the shaft on this level.

Operations are mainly confined to the Hecla ore body, which occurs along a practically vertical shear zone striking S. 45° E. in Burke quartzite beds that strike approximately north and south and dip 74° NE. Widths are very irregular and vary from 4 to 40 feet. The ore-mineral is a fine-grained galena with a small amount of zinc and is accompanied by very little siderite or pyrite. Heavy side pressure develops during stoping, due to the close sheeting of the ground.

Operations are also in progress in a smaller fissure-vein ore body, with similar ore, known as the East ore body, which is developed from the 900 level to a considerable distance above the No. 3 tunnel level. A number of other small veins, either paralleling or intersecting the main lode, have been developed and stoped to some extent.

In April, 1930, the mine was producing about 850 tons a day or ore averaging 9.5 to 10.0 per cent lead, a little zinc and 5 to 6 ounces of silver per ton with about 300 underground employees, of whom 270 were on the one main, or day, shift.

Mine Openings

Levels are designated by the distance below the shaft collar and have been driven

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off the main shaft at depths of 300, 600, 900, 1,200, 1,600, and 2,000 feet, with an intermediate level in the ore zone at 1,400 feet and a short intermediate at 1,800 feet. Below the 2000 level, development is at 200-foot intervals off an interior winze, and connection to the shaft will be on the 2800 level. The original level was the No. 3 tunnel level, above which there are some old workings near the surface. Development levels in the East ore body are at 150 to 200 foot intervals with connections on the No. 3 tunnel, 600 and 900 levels to the main ore body, with ore hauled on the latter to the shaft.

The main shaft has four compartments and is well west of the ore body on all levels and is connected to it by large rock drifts. A large three-compartment raise is carried up in the wall through upper worked-out areas to the No. 3 tunnel level for ventilation and as an emergency escapeway; a somewhat similar raise, for the same purposes, extends 1,500 feet from the No. 3 tunnel level to the surface. Raises through the ore body itself are numerous, for service, travel, and ventilation.

The Star mine of the Sullivan Mining Co., owned jointly by the Hecla Mining and the Bunker Hill and Sullivan Mining and Concentrating Companies, is operated through a 9,000-foot crosscut off the Hecla 2000 level. During April, 1930, on account of the low metal prices, development only was in progress in the Star mine.

Mining Methods

Practically all of the mining now is by a stull set and fill method of horizontal stoping. Stopes are timbered with heavy 9-foot high drift sets on 5-foot centers carried up like square-sets except that the caps extends across the width of the stope and are tightly blocked to the walls with at least 12 inches of blocking, locally termed "heading." Three compartment raises are driven to the level above previous to stoping, and stopes are carried up as 200-foot blocks working 100 feet each way from raise to raise. Tram cars are used for ore and waste. Filling closely follows mining, and practically only one floor is open at a time. Tops or bottoms of certain raises are bulkheaded so that the air flow passes through the open floor of the stopes.

In April, 1930, the active zone in the main Hecla ore body was between the 1600 and 2200 levels. Active working places included 13 large stoping sections in this ore body and 5 smaller sections in the East ore body. Development included three drifts and three raises. Operations in the adjoining Star mine included three small stope sections, 1 drift, 1 raise, and 1 (Star) shaft (raise).

Ventilation History

The mine is mechanically ventilated by a surface exhaust fan, and the active zone is 3,000 to 4,000 feet underground in warm rock. Improvement of comfort conditions on upper levels then active was the main reason for the mechanical installation, but conditions were not very bad at that time and other reasons for the installation were the desire to provide better protection in case of fire and to reduce timber decay by more positive direction of air-currents.

The mine operated to the 1600 level with but a few hundred feet of surface air natural-draft column, but conditions were then considerably improved by driving raise (No. 8C) from the East ore body to surface, thus increasing the surface natural-draft column to 1,500 feet. The mining system provides plenty of through raises, and conditions are said to

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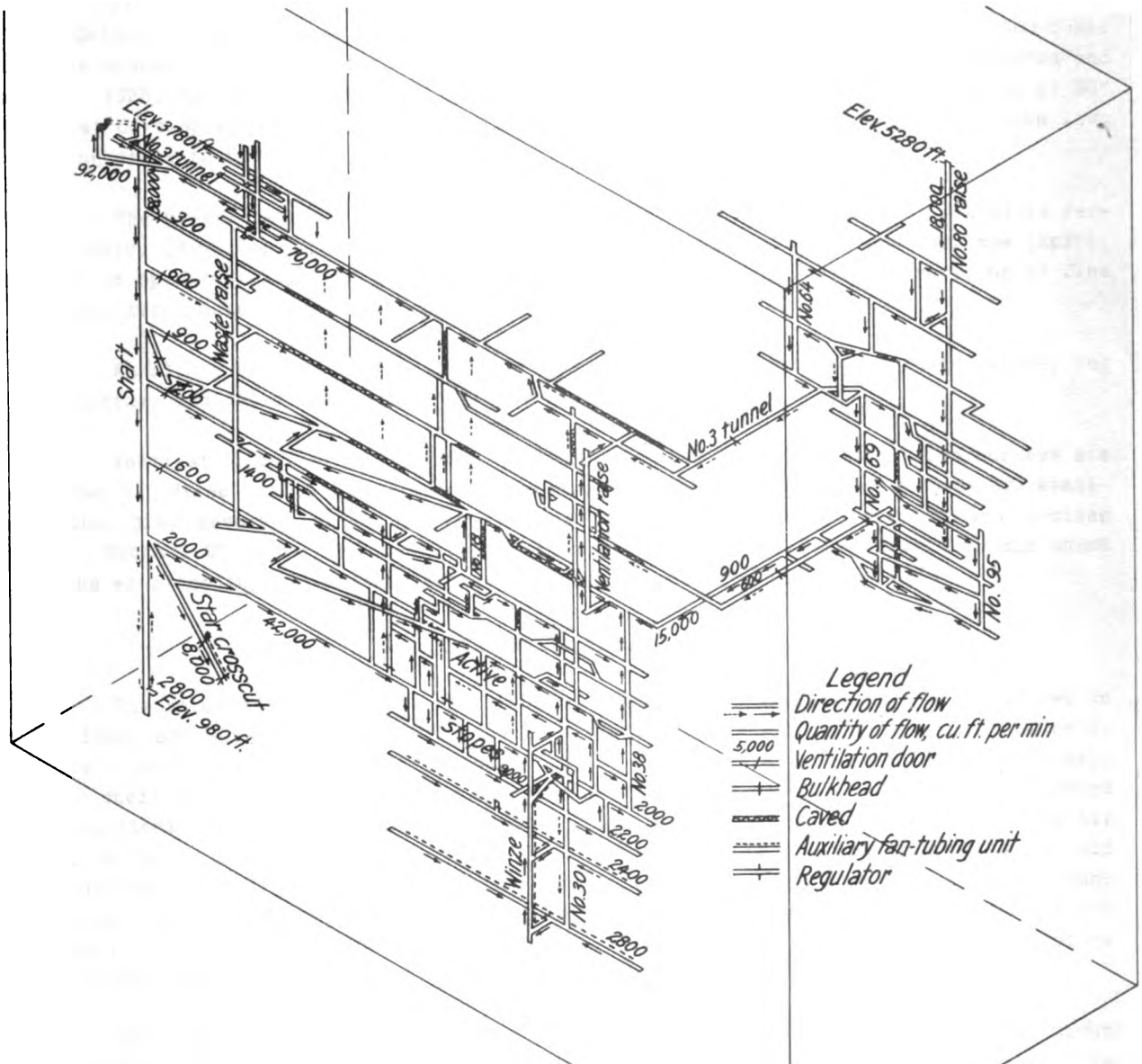

Figure 3.- Isometric projection showing ventilation system of the Hecla Mine, April, 1930

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have been quite good even after the 2,000-foot level was opened up, except over short periods and in lower development levels and in 1600 level stopes.

Where natural-draft ventilation was used, the main shaft was a constant downcast and the stopes were upcast to No. 3 tunnel. Upper levels off the shaft were closed off with doors and the intakes were limited to the 1600 and 2000 levels. No. 3 tunnel was normally outcast, but the No. 80 raise reversed with the seasons and occasionally the No. 3-tunnel and the 1600-level flows reversed. Records show total quantities usually less than 25,000 cubic feet per minute and rarely over 35,000 c.f.m. Air currents were practically saturated and in July, 1925, ranged from about 72 to 77° in the 2000 and 1600 stopes to a maximum of 80° in lowest development faces. The temperatures in the East ore body have always been low, averaging close to 50°.

The present surface fan installation is the original installation, placed in service in July, 1925. At first it was operated only during the day shift and even now (April, 1930) it is operated only from 2:00 a.m. to 3:30 p.m., since the general directions of flow and fairly large quantities of air are maintained by natural draft.

Auxiliary ventilation has been used only for development off an inside winze, for shaft sinking, and for driving the long Star crosscut.

Ventilation matters are handled by the chief engineer and ventilation surveys are made under his direction at approximately three-month intervals. Numerous records are available, including several partial surveys of wet and dry bulb kata (thermometer) cooling powers. Since 1928, data have been recorded on prints of a special ventilation map which shows the mine openings in sketch form in isometric projection (see fig. 3).

Distribution of Air Currents

The major elements of the distribution system, as determined by a brief survey in April, 1930, are shown on a sketch isometric projection of the mine openings in Figure 3, which is a rough copy of the more finished drawing used by the mine as a ventilation map. The main shaft is downcast and shut off by doors on all levels except the 2000 level, through which practically all the air goes to the main stoping zone in the Hecla ore body. The air upcasts through stopes to the 1600 level, then passes through inactive raises to the 900 level and then through a large ventilation raise offset in the wall rock to the No. 3 tunnel and out to the main exhaust fan. The No. 80 raise in the East ore body is also downcast and air downcasts through these workings to the 900-level connection, through which the return passes to the ventilation raise.

The fan was exhausting about 92,000 c.f.m. from the No. 3 tunnel, of which about 22,000 c.f.m. was surface air short-circuited through surface openings to the tunnel. The total supply for the mine was therefore about 70,000 c.f.m., equivalent to about 260 c.f.m. per man underground on the day shift. About 58,000 c.f.m. was intaking through the main shaft and 18,000 through the No. 80 raise of the East ore body; and approximately 4,000 c.f.m. of compressed air was being liberated underground. About 42,000 c.f.m. of the shaft air was going direct to the main stoping zone on the 2000 level, 8,000 c.f.m. was being discharged by a small fan through the Star crosscut to the Star mine, and the balance was the total of small (desired) leakages through single doors on the 900, 1200, and 1600 levels.

Of the 2000-level supply to the main stoping zone, about 9,000 c.f.m. was down-

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casting naturally to the 2200 level through west-side raises and returning to the level through east-end raises. Although the old stope connections below No. 3 tunnel were considered to be quite tightly filled, comparison of measurements of the total discharge from the ventilation raise with intake totals indicates that about 16,000 c.f.m. was exhausting through the stopes above the 900 to the exhaust tunnel. During the survey a tight bulkhead (used during shaft sinking) was removed from the cage compartment of the shaft at a point just below the 1600 level. Removal of the bulkhead increased the supply to the 2000 level about 10,000 c.f.m. and reduced the surface leakage by an approximately equal amount.

The intake shaft is extremely wet, and the mine is damp to wet practically throughout.

Performance of Main Fan

The main fan is a 7.0 by 3.5 foot Jeffrey, forward-curved-blade, double-inlet, centrifugal fan operated at 305 r.p.m. by belt drive from a 175-hp., 2300-volt, 435-r.p.m. induction motor. The fan is installed on the shaft-collar level at the top of a short rock raise driven off a crosscut connecting with the No. 3 tunnel inside an air-lock. It has a reversible housing of steel plate and concrete and an exceptionally long évasé discharge duct. The original évasé, expanding to 6.5 by 9.5 feet at 4.5 feet above the concrete fan chamber, was continued to a total height of 20 feet to accomodate a connection to a 6.5 by 8.5 foot wooden duct about 150 long which connects the évasé discharge of the fan to the downcast shaft just below the collar of the latter. One side of the extension of the évasé is a regulator door that can be set to deflect as much warm air as desired to the shaft intake to prevent formation of ice in the shaft during extremely cold weather. In normal winters the by-pass duct is used at intervals amounting to a total period of about two weeks and has been successful in preventing serious difficulties due to ice in the shaft at temperatures of minus 20° F.

The fan was handling 92,000 c.f.m. of air weighing 0.0655 pound per cubic foot with a static pressure near the inlet of 4.5 inches of water. Manufacturer's data indicate that the fan was operating about 7 per cent under maximum efficiency against higher-than-rated resistance conditions.

Condition and Dimensions of Airways

The major openings contributing resistance to flow are the main shaft, the 2000-level drift, the ventilation raise, the No. 3 tunnel, and the connection from No. 3 tunnel to the fan, all of comparatively large area. The main shaft is a four-compartment open-timbered shaft with two 4-foot 4-inch by 5-foot 2-inch skip compartments, a cage compartment of the same size, and a 2-foot 2-inch by 5-foot 2-inch obstructed manway and pipe compartment. Lagging placed flush with both sides of one set of center plates to brattice off the cage compartment from the adjoining skip compartment, and lagging set flush with the inner sides of the wall plates in the skip compartments to prevent excessive wear on the timber by falling rock, result in about half of the surface exposed to air flow being smooth-lined. Main haulage levels in waste have a minimum section of 8 by 8 feet and are usually larger. Drifts in the ore zone have a minimum clear section of about 8 by 9 feet, and at all stope sections the first floor is open, although considerably obstructed. Crosscuts are in rock and have an average section of about 5 by 7 feet. The usual raise is three sets long (sets on 5-foot centers), and extends the width of the ore with part of each set used for chute, timber-slide, and manway, respectively, and with the rest lagged off. Raises are on 100-foot

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centers and certain of them are bratticed off either at top or bottom to route air through stoping sections.

The ventilation raise has a 6.0 by 6.5 smooth-lined main compartment, a 3.0 by 3.5 lined timber-slide compartment and a small obstructed manway compartment. It extends from the 900 level to the No. 3 tunnel. Old raise openings between the 1600 and 900 levels are gradually closing in, and work has been started to extend this raise to the 1600 level.

The No. 3 tunnel is heavily timbered and in places has been stoped above the level. The minimum section is about 7.5 by 8.0 feet, but the average section is somewhat larger, possibly more like 8.0 by 9.0 feet. The crosscut to the fan is mostly unlined and about 8 by 9 feet in section. The fan raise is a round rock raise about 9 feet in diameter and 30 feet long. The top is concreted and shaped to form a well-rounded connection to the fan-inlet drift. It is about 3,000 feet from the fan drift along No. 3 tunnel to the ventilation raise. This opening is expensive to maintain and undoubtedly forms a high-resistance part of the flow circuit.

Doors

The ventilating system requires relatively few doors, but additional doors are installed as required for emergency use in case of fire. Single doors are used to shut off all levels but the 2,000 at the shaft, to shut off the No. 3 tunnel and 600-level connections to the East ore body, and to close off workings open to the surface. The portal to No. 3 tunnel is shut off by an air-lock.

Doors are exceptionally rugged and well made but are not exceptionally tight at the sill, as a little leakage is desired at most doors. The standard door is a single door made of three plies of cedar shiplap covered by No. 30-gage galvanized-iron. It is hung on three heavy bar hinges attached directly to a vertical concrete bulkhead having a 5 by 7 foot opening faced with 6-inch channel irons. The hinge bolts pass through 1-inch pipes set in the concrete. The door closes flush against the frame and may be easily changed from one side to the other. Doors are provided with both a bar latch and a counterweight. Those installed on a high-pressure air-lock have small pressure-release sliding doors and a pry bar to facilitate opening.

Auxiliary Ventilation

Auxiliary ventilation is used for long development drifts and raises. The only unit in use in April, 1930, was a No. 6 Sturtevant Multivane (forward-curved-blade) single-inlet fan installed at the winze on the 2000 level. It was blowing air through a 16-inch galvanized-iron pipe to a 22-inch pipe installed in the winze from which 16-inch pipe branches were carried to development faces on the 2,400 and 2,800 levels. It was direct-driven at 1170 r.p.m. by a 20-hp., 440-volt motor and was handling about 5,000 c.f.m. at a static pressure of over 7.0 inches in the discharge pipe.

The fan on the 2,000 level, from which air is sent through the Star crosscut to the Star mine, is a large auxiliary unit installed as a booster and blowing through 22-inch galvanized-iron pipe that extends through a long air-lock. This is a No. 10 Buffalo Forge (radial-blade) blower operated at 1,200 r.p.m.

The 9,000-foot Star tunnel, which has a minimum section of 8 by 8 feet, was ventilated during driving operations by auxiliary units in series exhausting through 22-inch

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galvanized-iron pipe and by a face fan blowing through 16-inch iron pipe. The latter was mounted on skids and moved up frequently. The final layout included three No. 8 Buffalo Forge blowers in series, direct-driven at 1,760 r.p.m. by 10-hp. motors; and a No. 6 Buffalo Forge blower as the face fan, operated at 1,200 r.p.m. by a 5-hp. motor.

When shaft sinking from the 2000 to the 2800 level in the main shaft was started, an auxiliary blower unit was installed on the 2000-level shaft station, but it was found that falling water in one compartment provided sufficient ventilation for the shaft sinking and the unit was not used.

Until recently all auxiliary units were used as exhausters and required iron pipe, which is continued in use with the blower units now used because it is preferred by the miners.

Very little compressed air is employed for air-motion cooling effect, as there are few places where there is an incentive for the miners to use it.

Natural Draft

Two major natural-draft columns are involved in the ventilation of the mine, that below the No. 3 tunnel to the 2000 level, and that above No. 3 tunnel to the top of the No. 80 raise. The 1,470 feet of downcast and upcast columns below the No. 3 tunnel create a draft that always acts in series with the fan and, was calculated as averaging about 0.9 inch of water for conditions as of April, 1930. The surface component of the 1,500-foot columns above the No. 3 tunnel produces large variations in this draft which throughout most of the year acts against the fan, so that when the fan is not running the No. 80 raise is a strong upcast. This condition holds, according to company records, whenever surface temperatures are below 55° and, without regulation of the main flow system, this raise upcasts against the fan pressures when the surface temperatures go below 15°.

There is also a considerable natural draft effect through the Star crosscut. In winter, with the booster fan shut down and the air-lock doors open, the quantities passing to the Star mine reach a maximum of 10,000 c.f.m., although in April only 8,000 c.f.m. was being circulated with the fan operating.

Air Conditions

Air Temperatures.- On account of the extremely wet conditions in the downcast shaft, average stope temperature conditions are practically constant throughout the year. According to the company records they now average about 3° lower, both wet and dry bulb, than before the fan was installed, even though the active zone has been lowered somewhat and the heat from lower development has been added to the west-end intake. Temperatures in the active stoping zone range from about 69 to 73° with a practically constant wet-bulb depression of 0.5°. Dry-kata-cooling powers range from about 5.0 to 8.0 and wet-kata-cooling powers from about 10 to 16. The East ore-body workings are cold and wet and have average temperature conditions ranging from about 40 to 60°, depending on the place and season. The Star workings are reported also to be cold and wet.

Some heat is generated in the filled stopes, and low-velocity flows through caved openings on upper nonoperating levels attain temperatures as high as 77° in saturated air. The winze return air is saturated at 76°, and temperatures at active development faces on the 2400 and 2800 levels range from 77 to 80° with wet-bulb depressions up to 2.5°.

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The shaft collar is enclosed and a considerable amount of heat that is generated in the enclosure is drawn into the downcast shaft.

Rock Temperatures.- Rock temperatures in virgin ground were determined as 77° on the 2000 level, 79.5° on the 2400 level, and 82.2° on the 2800 level. These temperatures indicate a constant increase of 1° with each 154 feet increase in depth.

Air Quality.- Analyses and pertinent data regarding six air samples taken during this survey are shown in Table 5. They show air of good quality throughout the active zone. The increase in carbon dioxide in the returns indicates a similar action to that taking place in the Morning mine, and considering the surface leakage, on about the same scale. The increase is probably equally due to timber decay and to chemical reactions of air and moisture with siderite in the gobs; it does not affect the air supply to active workings.

Ventilation Costs

With the exception of the main fan installation and the ventilation raise, all ventilation expenditures are charged direct under three headings—labor, power, and supplies. No charge is made for compressed air. The main fan is operated only 13 hours a day. Total and unit costs for the last five years are shown in Table 6.

Table 5. - Analyses of mine air samples, Hecla mine, April 16-19, 1930

Location and Description	Wet bulb, °F	Dry bulb, °F	Volume, c.f.m.	Chemical Analyses				
				CO_2	O_2	N_2	CO	CH_4
East face of 2400-level fan-pipe ventilated development drift	75.0	77.5	Small	0.14	20.54	79.32	0.00	0.00
Mining floor of 2000-level stope No. 9-14	71.0	71.5	Small	.27	20.52	79.21	.00	.00
Small stope up 5 floors off 1200 level near No. 18 raise in return air zone	76.5	77.0	Negligible	.40	20.44	79.16	.00	.00
Total return air current in fan drift	61.0	61.0	92,000	.36	20.60	79.04	.00	.00

Table 6. - Ventilation Costs, Hecla Mine

Year	Operating Costs				Unit costs in cents per	
	Labor	Power	Supplies	Total	Ton of ore	Lb. of lead
1925	$3,005	$321	$1,613	$4,939	1.500	0.009
1926	974	1,771	628	3,372	.974	.006
1927	1,001	1,630	726	3,357	1.084	.006
1928	707	1,658	203	2,568	.821	.004
1929	378	1,669	114	2,161	.695	.004
			Total operating	$16,397		
			Fan installation	14,615		
			Ventilation raises	33,311		
			Total for 5 years	$64,323		
			Average per year for 5 yrs.	12,865	3.997	.023

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Under present conditions, ventilation air costs about 0.00006 cent per cubic foot on a total charge basis, but only about 0.00001 on the basis of operating charge only. The ventilation system uses about 160 continuous horsepower during the operating shift or 0.19 hp. per ton of production. The main fan uses 150 hp. and produces about 470 c.f.m. of effective air supply per horsepower. Recent power records show that the ventilation system, excluding the Star fan, requires about 7.0 per cent of the electrical power used by the mine.

GOLD HUNTER MINE

The Gold Hunter mine of the Gold Hunter Mines, Inc., is operated through a 4,700-foot crosscut tunnel (No. 6) entering the north side of the mountain about 1 mile east of Mullan, at an elevation of 3,410 feet. The vein outcrops on the side of a steep gulch, the highest openings being about 1,300 feet higher than the main-tunnel level. Although a prospecting winze has been carried to a depth of 1,800 feet below the tunnel, the lowest operations in May, 1930, were on the 800 level, 800 feet below the tunnel, and practically all of the stoping operations were above the tunnel level.

The conditions of ore occurrence, the methods of mining, and the layout of openings greatly resembles an earlier stage of the Morning mine. The ore zone is practically vertical and consists of parallel veins aggregating widths of 5 to 50 feet, with an average of 40 feet above and 30 feet below the No. 4 tunnel. Present operations are on veins alongside old stopes and mostly on material that was too low in grade to be mined originally.

In April, 1930, the mine was producing about 500 tons a day of ore averaging 4.0 per cent lead and 1½ ounces of silver per ton, with practically no zinc content. Operations were on one shift with 105 men underground.

Mine Openings

The mine was developed originally by adit drifts of successively lower depth down to No. 5, which is 640 feet above the main crosscut tunnel, No. 6. Separate raises, used as shafts, extend from No. 6 to the No. 5 tunnel level, from No. 5 to No. 4, and from No. 4 practically to the surface. Below the No. 6 tunnel, levels are developed at 200-foot intervals to the 1200 level (omitting the 1,000 level) off a three-compartment shaft set a short distance from the ore zone.

Mining Methods

Mining is by a stull set and fill method resembling that used at the Morning mine, except that the timbers are not so large and filling does not follow extraction so closely. The result is that five or more 9-foot floors are open at a time. Raises are large and have plenty of openings for air to get into stopes, which, however, do not always have raises through to an upper level.

Operations in May, 1930, extended from 800 feet below the No. 6 tunnel level almost to the surface 1,300 feet above it, and included about 12 widely scattered stopes.

Ventilation

Ventilation is entirely by natural draft except for the idle 1200 level, which is ventilated by an auxiliary unit whenever it is necessary for a pumpman to visit a pump on this level. It is reported that the ventilation of the mine has always been exceptionally

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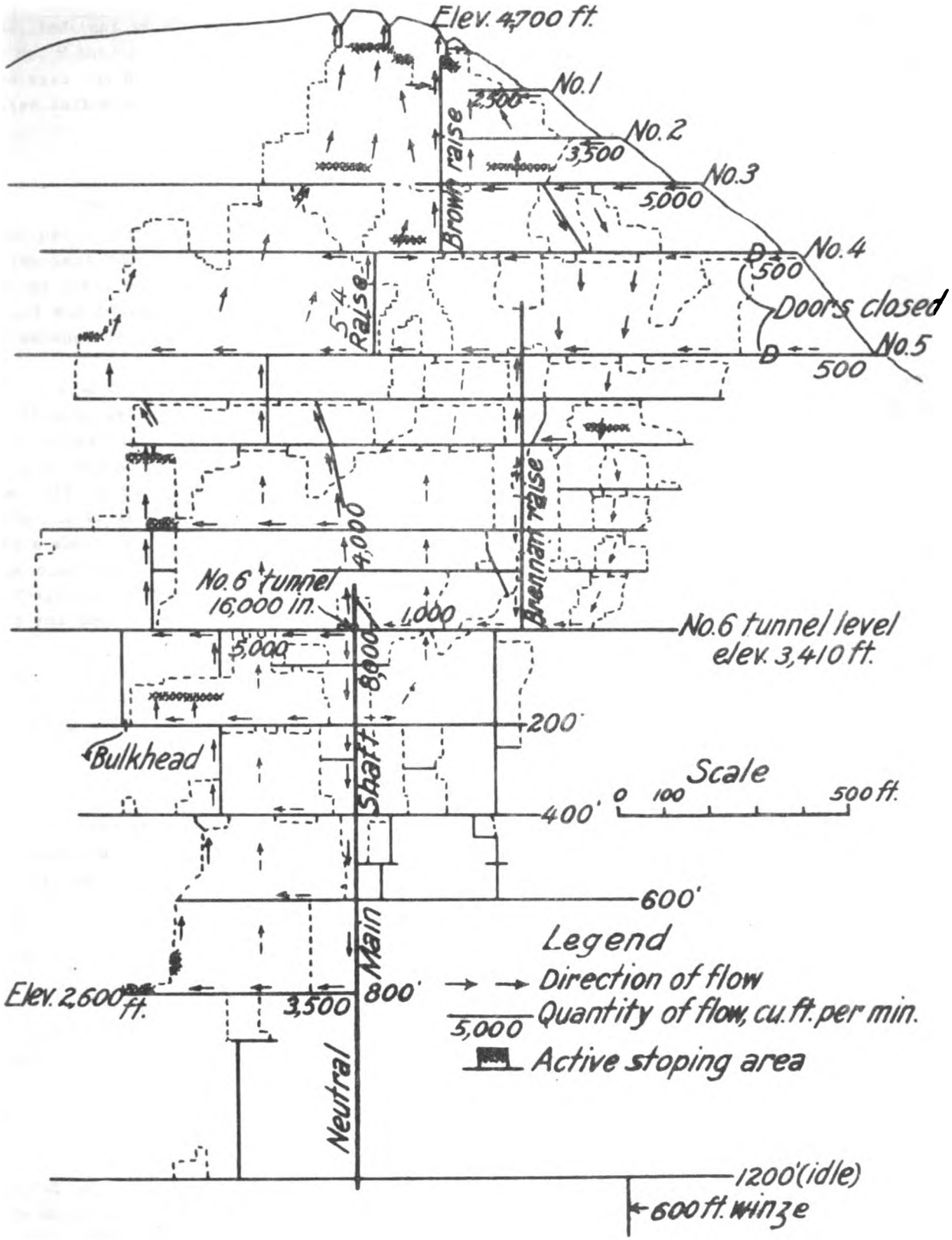

Figure 4.–Diagrammatic vertical projection of the Gold Hunter Mine showing ventilation conditions May 29, 1930.

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good, and that in winter it is necessary to shut off most of the surface openings, including the No. 6 tunnel, to prevent serious difficulties with ice formation in the drainage ditches. Even with the No. 6 tunnel shut off by a good air-lock, the small intake leakages have resulted in ice formations up to 2,000 feet from the portal in extremely cold weather.

Distribution of Air Currents

The ventilation is said to reverse when the surface temperature is about 60°, but quiet periods are never more than a few hours long. Surface temperatures are below 60° most of the year and rarely go above 60° at night in summer. Normally, the tunnels are incasts and the shaft downcast; a few east-side stopes are downcast from No. 3 to No. 5 tunnel with Nos. 4 and 5 tunnels shut off; and the rest of the stopes and main raises are upcast with the exhaust passing out surface glory holes.

A brief survey of the distribution, on May 29, 1930, when the surface air was practically saturated (steady rain) and at a temperature of 50°, showed conditions to be as outlined in Figure 4, a sketch showing the vertical projection of the mine workings. The doors on the No. 4 and No. 5 tunnels were closed; those on Nos. 1, 2, 3, and 6 tunnels were open. All of the open tunnels were intakes; 2,000 c.f.m. in No. 1, 3,500 c.f.m. in No. 2, 5,000 c.f.m. in No. 3, and 16,000 c.f.m. in No. 6. Leakages on single doors on Nos. 4 and 5 were about 500 c.f.m. each. The total supply at surface exhaust air conditions, including some compressed air liberated underground, could not be measured, but was estimated as approximately 30,000 c.f.m., equivalent to about 290 c.f.m. per man underground. This estimate was made at a time when the natural draft was far from a maximum.

At this time about 8,000 c.f.m. was downcasting through the main shaft, and 3,500 c.f.m. was passing to the vein on the 800 level. Although there are two openings, there was no perceptible flow in the shaft below the 800 level.

Conditions and Dimensions of Airways

The openings through stoping zones oppose only a very slight resistance to flow. The major resistances are the small drift tunnel intakes, which are but 5 by 6 feet in average section and are irregular; and the No. 6 crosscut tunnel, which, although straight and composed of lined and unlined sections averaging close to 50 square feet in cross-sectional area, is 4,700 feet long. Crosscuts between stoping zones are also small, not over 5 by 7 usually.

The main shaft is an open-timbered shaft with three 4.5 by 5.5 compartments, one of which is considerably obstructed. The main raises comprise stull-set timbered openings extending the full width of the vein and two sets long, which offer large openings for flow.

Doors

Air-locks are provided on all tunnels both for diverting the flow and as protection against surface fires. Usually only one door of the lock is used. Doors on upper tunnels have only small openings such as are required to pass men; these doors are well fitted into a wooden-frame bulkhead stuffed tight with rags.

For winter operation the No. 6 tunnel is equipped with two ventilation doors,

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forming an air-lock the length of the tunnel, and also has a horizontally-hung, iron-plate fire door near the portal swung from a concrete frame with the face set on a pronounced batter. This is tripped by a rope which extends to the portal and into the adjacent timbered passageway for a little distance; in case of fire the flames would sever the rope and thus shut the door. Operation of the door also cuts the current on the trolley wire by dropping a section attached to the door.

The outer door of the air-lock is often used singly in cold weather. This is an electrically-operated sliding door of local design operated by a small motor set in motion by rope pulls attached to electromagnets. This design has been patented by the master mechanic, L. M. Norris.

The inner door is a substantial three-ply wooden door spanning a 4.75 by 7.0 foot opening in a wooden frame tightly stuffed with rags to make a tight seal to the rock. It is braced with a 45° diagonal strip of 4-inch channel iron, is carried by heavy bar hinges, and is provided with a good latch and a 6-inch circular glass peephole.

Air Conditions

Air temperatures are always comfortably cool to cold. The mine is damp to wet throughout and the air is close to saturation everywhere, although few foggy zones develop. Underground temperatures are but little affected by the change in seasons. In May, 1930, the temperatures ranged from about 50 to 60° with not over 0.5° wet-bulb depression. The east-side workings averaged about 55° and the west-side workings about 60°. The lowest active face, a silling-out operation on the west end of the 800-foot level, had temperatures of 62° dry bulb, 61.5° wet bulb.

No rock temperature data are available, but the air temperatures indicate low temperatures and a low gradient, probably very close to that experienced at the Morning and Hecla mines.

No rock temperature data are available, but the air temperatures indicate low temperatures and a low gradient, probably very close to that experienced at the Morning and Hecla mines.

One air sample, taken in the lowest working face on the east end of the 800 level, analyzed 0.24 per cent carbon dioxide, 20.53 per cent oxygen, and no carbon monoxide or methane. This sample indicates that the quality of the air throughout the mine is fair, although it is probable that the upcast currents near the top of the west side workings have a higher carbon-dioxide content due to timber decay and chemical reactions in the waste filling.

PAGE MINE

The Page mine of the Federal Mining and Smelting Co. is operated through an inclined shaft near the head of a gulch about 4 miles west of Kellogg. It has been intermittently developed since 1906, but has been operating steadily only since 1925. The mine has about a mile of horizontal development, including connections to two prospect tunnels of 52 and 113 feet below the shaft-collar elevation, which is 2,677 feet. The lowest level is 920 feet vertically below the shaft collar.

Operations are on a fissure vein cutting the Revet quartzite. It strikes about east and west and has a very variable dip that averages about 52°.

The mine employs 70 men underground, of whom 65 are on the main day shift, and

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produces about 300 tons a day of ore averaging 9 per cent lead, 2.5 per cent zinc, and 2½ ounces of silver per ton.

Mine Openings

The mine is operated through a shaft sunk on an incline of 52° which contains two compartments and a manway. Levels are developed at 300-foot intervals along the incline with the lowest level at 1,200 feet. The present producing zone is cut off by a fault on the west has been stoped from the 300 to the 600 level, is now being stoped between the 600 and 900 levels, and is being developed between the 900 and 1,200 levels. The 600 and 900 levels have been prospected a long distance east of the shaft and some stoping has been done above the 600 level off a raise connection to the Black Hawk tunnel. The 600 level is also connected to the Curlew tunnel by a raise and to the 900 level, on the east side, by a single raise.

Mining Methods

A standard method of square-set and fill mining with breast stoping is employed. Through raises are driven up to the level above at intervals of 100 to 200 feet, depending on vein widths. Stopes are started from the raises, but although they are carried up simultaneously on a level the stopes are not necessarily interconnected. Waste filling follows extraction closely. Usually all or parts of three floors are open, one for mining, one for mucking, and one for tramming.

In May, 1930, ten stopes and three development raises were being operated.

Ventilation

Ventilation is by natural draft entirely, except that auxiliary fans are used in sinking the shaft and driving long development faces. Ventilation is reported to be good practically all the time, although only a small surface motive column is involved. Ventilation reverses twice a year. The shaft is upcast in winter and spring, and downcast in the summer and fall. Usually there is a week or two of wavering air currents before the change is established but the most recent change over was an abrupt one without later reversals.

Distribution of Air Currents

A brief survey of the distribution of air currents was made on May 12, 1930, with natural drafts close to a minimum and with surface temperatures ranging from 50 to 60°. The general results are recorded on the sketch showing a vertical projection of the mine workings (fig. 5). At this time, the surface component of natural draft was practically negligible and flow was due primarily to the difference in average temperatures between the cooler downcast column, as influenced by contact with rock surfaces cooled by the air of the preceding colder weather, and the warmer upcast column, as influenced by rock temperatures and local sources of heat in the stoping zone and in the shaft.

Unfortunately, the conditions encountered on the day of the survey were not normal in that the Curlew tunnel had caved tight just previous to the survey, thus shutting off one inlet. However, observations made less than a month previous showed that the Curlew intake air was then crossing directly to and up the shaft, so that the loss of this intake was not affecting the ventilation seriously at the time of the survey.

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Air intaking through the Black Hawk tunnel was traveling in a continuous current through raises and parts of the 600 and 900 east drifts to the shaft at the 900 level, where the major portion crossed the shaft to the 900 west. Above the 900 level, the shaft was neutral and below there was a slight downcast current to the 1200 level on which the air passed to an upcast raise at the west end. The total flow upcasted through stopes to the 600 level; part continued up raises to the 300 level and passed out to the shaft, and part passed directly to the shaft on the 600 level. Above the 600 level the shaft was upcast to the surface, with practically all of the flow in the manway compartment.

The quantity as measured on the east 900 level was 4,000 c.f.m. and about 5,000 c.f.m. was being exhausted at the collar of the shaft, the increase being due to compressed air liberated underground, small changes in air density, and a few hundred c.f.m. from the Curlew caved intake.

The total supply of 5,000 c.f.m. is equivalent to about 80 c.f.m. per man underground on the main shift. There are no records of the maximum winter flows, but they are reported to be large even when, to prevent freezing of a water line, the Black Hawk tunnel is considerably throttled.

The manway compartment of the shaft is bratticed off, but numerous openings to the adjoining compartment exist. The fact that practically all of the upcast flow occurred in the smallest and most obstructed compartment of the shaft is attributed to a small production of heat in this compartment by the pump column and compressed-air pipe.

Condition and Dimensions of Airways

Most of the resistances to flow are on the upper levels and the surface connections to and through the Curlew and Black Hawk tunnels. The Curlew intake to the 600 level includes a 630-foot crosscut tunnel, a 200-foot drift, and a 450-foot raise. The Black Hawk intake is somewhat similar. The drifts are comparatively small and sinuous through the old upper levels, averaging 5 by 6 feet or smaller. On the lower and more recently developed levels, the drifts are uniformly 6 by 7.5 feet timbered and are quite regular.

Standard raises are driven on the incline of the vein with two timbered compartments, a chute and a manway. The latter is available for air flow and has a clear area of 4 by 4.5 feet without obstructions. The Curlew and Black Hawk raises have three 3 by 4.5 compartments, of which two are open for air flow.

The shaft is an open-timbered, three-compartment shaft sunk on an incline of 52° in the footwall of the Curlew vein. It has two 4.5 by 5.0 foot skip compartments and a 5.0 by 5.0 foot manway with a clear opening in the latter of about 4.0 by 5.0 feet. Men and material are carried in either skip. The skip compartments are therefore bratticed off from each other and from the manway, with the result that movement of the skips produces a very considerable pumping action in the flows west of the shaft.

Timber-decay fungi are quite abundant throughout the mine, and zones of fog are of frequent occurrence.

Doors

No attempt is made to control the flow except that small doors are located at the

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portals of the two surface tunnels to throttle the flows in cold weather and give protection from surface fires. Wooden buildings adjoin the shaft collar, and doors for the latter are being considered.

Air Conditions

Air temperatures are always comfortably cool in the operating zone and are practically constant at 60 to 63°. The mine is damp throughout and wet-bulb temperatures are rarely more than 1° below dry-bulb temperatures. At the time of the survey, the temperatures of the downcast columns were 49° at the 600 level east and the upcast column ranged from about 62° at the 1200 level to 59° at surface.

No rock-temperature data are available. Air and water temperatures, however, are much higher than at equivalent depths in nearby mines and indicate a much more rapid increase of rock temperature with depth than in the large mines of the district.

An air sample from the top of the stoping zone analyzed 0.38 per cent carbon dioxide and 20.32 per cent oxygen, indicating that the quality of the mine air is fair but that some vitiation by timber decay and chemical reactions is taking place.

DAYROCK MINE

The Dayrock mine is a typical small mine worked through side-hill adit tunnels. The mine is operated through two adit tunnels in the west side of Ninemile Gulch about 3 miles north of Wallace. The adits are about 100 feet apart vertically and connect with a small two-compartment inclined shaft. Three lower levels are developed off the shaft on 100-foot vertical intervals.

The major operations are in a comparatively long stoping zone inside the shaft between the 200 and 300 foot levels (below the upper adit and shaft collar).

The dip of the Dayrock vein averages about 60°. Widths vary up to a maximum of 15 feet. Stoping ground is developed by large two-compartment raises on 25-foot centers. About every fourth raise is carried to the level above. Stopes are mined as open stull stopes, and filling closely follows extraction. Stopes are carried up in 50-foot sections and require very little timbering except for chutes.

The mine produces about 130 tons a day of milling lead-silver ore and is operated in two 7:00 to 3:30 shifts, with 25 men underground on the day shift and 18 on night shift.

Ventilation

Ventilation is entirely by natural draft, except that long dead ends are ventilated by small booster auxiliary units which exhaust the blasting smoke and discharge it into the shaft above the stope returns. It is reported that the ventilation of the mine has always been exceptionally good, even though air currents reverse twice a year and are uncertain in direction for a short period at the time of the change overs, June and October.

A brief survey of ventilation conditions was made on May 7, 1930, during an exceptionally cold morning. Air intaking through the lower adit (100 level) downcasted through

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the first open raise to the 200 level and traveled west to the shaft, through which a large proportion upcasted directly. A small amount downcasted through the shaft to the 300 level and traveled west on this level to the stoping zone through which it upcasted and returned to upcast raises adjacent to the shaft, finally entering the shaft on the 100 level. The exhaust from the shaft passed out the upper tunnel to surface.

At 7:30, when the surface temperature was at 34°, about 6,000 c.f.m. was entering the mine; at 10:30, when the surface temperature was at 47°, the intake was reduced to 2,500 c.f.m. Much of the intake short-circuited to the return, and the supply through the main stoping zone was only about 1,000 to 1,500 c.f.m. Including compressed air, the total supply over this short period of one morning ranged from about 120 to 250 c.f.m. per man underground.

Air Conditions

Temperatures throughout the west side were practically constant at 52° wet bulb and 53° dry bulb, and even though air currents were barely detectable in the workings most remote from the shaft, an air sample showed only 0.05 per cent carbon dioxide and 20.80 per cent oxygen, that is, air almost as good as surface air, indicating that the high carbon-dioxide content of air samples from the other mines of the district is due more to timber decay (very little timber in this mine) than to chemical reactions. Fungus is present on most of the timber, and foggy zones and recirculation of air currents are quite common throughout the mine.

No doors are used to control the air currents, but good iron-plate doors, swung from heavy timber frames in concrete bulkheads, are installed near the portals of the adits. These are provided with counterweights and held open by latches which may be tripped, by means of a rope, from the outside.

CONCLUSIONS AND RECOMMENDATIONS

The mines of the district enjoy such marked natural advantages with respect to ventilation that the subject has not been a very live one. Only the three large and deep producing mines employ primary mechanical ventilation, although long dead-end openings throughout the district are driven with the aid of small auxiliary units, usually exhaust units used in conjunction with small-diameter galvanized iron pipes.

Detailed data have been given for the three large mines, and conditions in the smaller mines have been outlined with the addition of a few notes made from very brief surveys of three of them.

Conditions that could be remedied, at an expense within limits set by the advantages to be derived, were found in all the mines visited. A few doors placed at strategic points would improve average conditions in most of the small naturally-ventilated mines by preventing short-circuits and recirculation, and by maintaining larger temperature differences underground which would result in better drafts, particularly at change-over periods.

Mechanical Ventilation of Small Mines

Considering the occurrence of timber-decay fungi everywhere underground, the hindrance to operations at times by zones of fog, and the lack of control of direction of currents, it is considered feasible and well worth while for all of the small operators to

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equip their mines with primary fans. Their main purpose would be as insurance against fire risks. Whether they should be operated continuously or intermittently would depend primarily on the advantage to be derived from reducing timber-decay and maintenance of openings, although there are also important advantages as regards safety in that the direction of air-currents is constant and the intake currents are directed through the major openings used by the men in entering and leaving the mine.

Improvements at Large Mines

Informal recommendations relating to possible improvements in air conditions were made to the operators of the three large mines.

At the Bunker Hill and Sullivan mine the air samples taken during the survey revealed a surprisingly high carbon-dioxide content in the intake air, which is apparently a seasonal condition to a large degree and is due to travel of intake air through old workings. A general rearrangement of the distribution system was proposed to improve the purity of the intake and secure a cooler supply to a greater number of working places by a more effective use of the main shafts as intake airways.

At the Morning mine the natural obstacles to satisfactory ventilation are large. The stopes are in warm ground that develops tremendous side pressure and the main return airway passes through stoped-out zones. Large leakages to the return above the stoping zone reduce the supply of air to the stopes, which on account of the difficulty of holding open the raises in the vein, are ventilated as dead ends by auxiliary units. Use of these units has advanced to a high degree of efficiency, but the method has proved unable to provide satisfactory conditions; for this reason an attempt is to be made to provide stopes with through raises to maintain through circulation. The installation of a large booster fan on the 2450 level at the bottom of the air raise and further attempts to seal the raise where it passes through old stopes are also contemplated.

At the Hecla mine no particular difficulties of ventilation have been encountered, except one relating to power consumption as affected by large surface leakages into the main exhaust airway. Full-time operation of the main fan will be desirable to maintain comfortable air conditions when the 2800 level is connected through; moreover, it is debatable whether the daily reversal of air currents in the East ore body does not result in timber decay that more than offsets the power saved by shutting the fan down overnight. The introduction of fungi spores from the return air current into the shaft intake current at times when part of the return is deflected into the intake to prevent formation of ice, is also a debatable procedure, although the time intervals may be so short as to cause no appreciable increase in timber decay.

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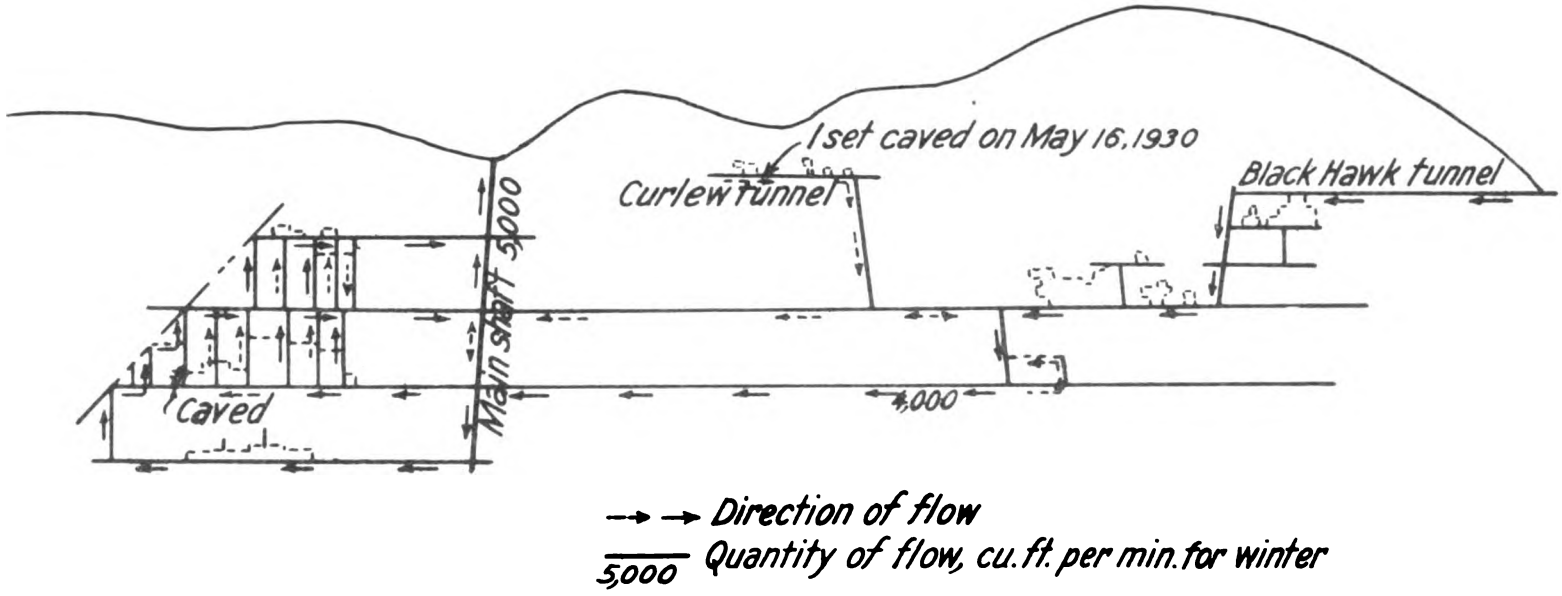
I set caved on May 16, 1930
Curlew tunnel
Black Hawk tunnel
Main shaft 5,000
Caved
4,000
→ → Direction of flow
5,000 Quantity of flow, cu. ft. per min. for winter

Figure 5.- Diagrammatic vertical projection of the Page Mine showing ventilation conditions on May 12, 1930

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